GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: 10/27/80

Project Title: In-Plant Demonstration of a Machnozzle as a Fabric Predrying Device

Project No: A-2776 (Subproject is E-27-689/Carr/T.E.)

Project Director: Wiley Holcombe

Sponsor: Department of Energy; Oak Ridge, TN

Agreement Period: From 9/1/80 Until ~~5/31/81~~

Type Agreement: Contract No. DE-AS05-80-CS-40350 dated 9/25/80

Amount: $34,466 A-2776
34,886 E-27-689
$69,352 TOTAL

Reports Required: Final Report

Sponsor Contact Person (s):

Technical Matters

John Rossmeissl
Industrial Energy Conservation
Department of Energy
20 Mass. Avenue
Washington, D.C. 20545

Contractual Matters
(thru OCA)

Allen Askew
Contract Management Branch
Procurement & Contract Division
Oak Ridge Operations
U.S. Department of Energy
P. O. Box E
Oak Ridge, TN 37830
615/576-0642

Defense Priority Rating: N/A

Assigned to: TAL/AED (School/Laboratory)

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Other Sonya Newkirk

CA-3 (3/76)

GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION SHEET

Date 2/22/82

Project Title: In-Plant Demonstration of a Machnozzle as a Fabric Predrying Device

Project No: A-2776 (Subproject is E-27-689/Carr/TE)

Project Director: Wiley Holcombe

Sponsor: Depart. of Energy; Oak Ridge, TN

Effective Termination Date: 8/31/81

Clearance of Accounting Charges: 8/31/81

Grant/Contract Closeout Actions Remaining:

- [ ] Final Invoice and Closing Documents
- [x] Final Fiscal Report
- [x] Final Report of Inventions
- [x] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other ____

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FORM OCA 10:781

A-2776

Monthly Project Status Report - No. 1
In-Plant Demonstration of a Machnozzle
As a Fabric Predrying Device

During October, preparation for the in-plant demonstration was begun. On October 2, 1980, Georgia Tech personnel (W.W. Carr and W.D. Holcombe) met with J. P. Stevens & Co., Inc., Delta #1 plant personnel to discuss the in-plant demonstration. The J. P. Stevens & Co., Inc. representatives included:

R. L. Gill, Finishing Plant Manager
F. H. Toney, Finishing Plant Superintendant
M. F. Wynn, Quality Control Superintendant
W. R. Burnett, Corporate Engineer
E. C. Mosley, Plant Energy Coordinator

E. C. Mosley, the plant energy coordinator, will serve as the J.P. Stevens Co., Inc.'s project manager.

The purpose of the meeting was to work out the details of conducting the in-plant demonstration so that preparation for the project could be started immediately. The subjects discussed in the meeting included:

- selection of the continuous range to be used for the in-plant demonstration
- installation of equipment for measuring various steam flow rates needed to characterize the drying process with and without the machnozzle
- design and installation of fixtures for mounting the machnozzle on the continuous range
- design and installation of the condenser system for recovering energy in the steam used by the Machnozzle

- modifications to the continuous range required for the installation of the machnozzle, instrumentation, and condenser
- moisture monitoring devices

The Delta #1 Plant's Number 6 Range was selected for the in-plant demonstration. The range has recently been instrumented for a corporate research project. Data from this system will be available during our demonstration runs in addition to the data taken by instruments installed specifically for the machnozzle in-plant demonstration.

Design of the machnozzle fixtures and condenser system was begun. Preliminary drawings have been prepared. Work to finalize the design is being conducted.

Efforts to procure moisture monitoring equipment for the in-plant demonstration have been made. Several potential suppliers of moisture monitoring equipment were contacted and the possibility of using their equipment was discussed. The four types of moisture monitoring devices being considered are:

- microwave
- dielectric
- infra-red
- electrical conductivity

Since fabric moisture regain at various locations in the dryer section of the range is to be measured, a broad range of moisture regain (0 to 100%) must be monitored. Due to the wide range of moisture regain to be measured, it is doubtful that a single device will be adequate for the required measurements. One of the suppliers has tentatively agreed to supply two types of moisture monitoring devices for the in-plant demonstrations. One of the devices measures regain over the range 0 to 30%, and the other device measure regain over the range 20 to 100%. The company's formal agreement to supply the equipment will be obtained as soon as possible.

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF TEXTILE ENGINEERING
ATLANTA, GEORGIA 30332
(404) 894-2490

December 5, 1980

Mr. David R. Klimaj
Department of Energy
Conservation and Solar Energy
Industrial Programs, CS-40
Forrestal Building
Washington, DC 20585

Subject: Contract No. DE-AS05-80CS40350
In-Plant Demonstration of a
Machnozzle as a Fabric Predrying
Device

Dear Mr. Klimaj:

The monthly Project Status Report for November 1980 for the subject contract is enclosed.

Please contact me in the event you have any questions regarding this report.

Sincerely,

W. W. Carr
Principal Investigator

cc: Office of Contract Administration
Project File
W. D. Holcombe
W. C. Carter

Monthly Project Status Report - No. 2
In-Plant Demonstration of a Machnozzle
As a Fabric Predrying Device

Preparation for the in-plant demonstration was continued in November 1980. Efforts during the month were directed at procuring instrumentation needed for monitoring steam flow and fabric moisture and designing machnozzle fixtures and a direct contact condenser.

The necessary orifice plates and flanges for monitoring steam flow during the in-plant demonstration have been ordered. Delivery is expected in early January. One fixed steam flow monitor has been located at Georgia Tech that will be available for the in-plant demonstration. Potential vendors have been contacted about a second steam flow monitor. It will be ordered in mid-December.

Mahlo-America, Inc., located in Spartanburg, South Carolina, has agreed to supply moisture monitoring equipment for the in-plant demonstration. Due to the wide range of moisture regains to be measured, two types of devices will be used. Mahlo's Aqualot, Type HMF unit (a microwave apparatus) will be utilized to measure moisture regain before and after the Machnozzle. This unit has the capability of measuring moisture levels between 20 and 300 grams per m^2 with an accuracy of $\pm$ 0.5 grams per m^2. Since the weight of fabric to be processed during the in-plant demonstration is approximately 3.7 ounces per square yard, the range of moisture regain that can be monitored with Mahlo's Aqualot unit is from approximately 16% to 240%. The unit has the desirable characteristic of being a non-contact apparatus, which is particular advantageous when measuring high moisture regains. The possibility of incurring sensor fouling due to the high quantity of water content on the fabric will be avoided.

Malo's DB7-7 portable moisture monitoring device will be used to measure moisture regain below 16%. The range of moisture regain that this device (an electrical conductivity apparatus) is capable of measuring is from approximately 1 to 30%.

Mahlo has agreed to provide its Aqualot, type HMF, unit at a rental rate of $960 per month plus set-up charges not to exceed $500. Mahlo has also agreed to provide one of its DMB-7 portable meters at no charge.

The Aqualot unit to be used during the in-plant demonstration was not in stock at Mahlo's Spartanburg office and thus had to be ordered from the home office in Germany. Delivery of the unit from Germany could not be made immediately due to the unavailability of a component of the unit. As a result, the in-plant demonstration could not be begun in December. Juergen Klopsch, Executive Vice President of Mahlo-America, Inc. has confirmed that the unit will be made available for the in-plant demonstration no later than the end of January 1981. Mr. Klopsch has stated that the delivery date will be improved if at all possible.

Atmospheric Sciences, Inc. (ASI), located in Sunnyvale, California, produces moisture detection systems for the wood and wood-product industries. ASI's moisture monitoring devices are dielectric-type instruments. Although the ASI devices have not been tested on textile products, representatives of ASI feel these devices are suitable for monitoring moisture in textiles. One of ASI's instruments will be tested at Georgia Tech to determine the instrument'scapabilities. If the instrument is found to be suitable for accurately monitoring moisture regain in fabrics, the instrument will be rented and used as a back-up device during the in-plant demonstration.

The design for the direct contact condenser was completed during

November and a shop drawing was prepared (this shop drawing is attached). Materials and parts have been purchased for the condenser and construction will begin in early December. The condenser should be ready for testing before the holidays.

A visit was made to Clemson to check out the preliminary design for the Machnozzle mounting fixture. This design did not provide sufficient space for the fabric moisture monitoring equipment. An alternative design that will provide sufficient room for the moisture monitor (See Figure 1) was devised during this visit. Construction of the mounting fixture will begin as soon as a final design is approved by J.P. Stevens Co., Inc. plant engineer.

PARTS LIST

Part Number	Quantity Required	Description	Material	Special Instructions
101	3	Weir Mount	.070 in steel	brake and weld inside weir-120° apart
102	1	Inside Weir Tray	.070 in steel	roll and weld
103	1	Outside of weir tray	.070 in steel	roll and weld
104	1	Bottom of weir tray	.070 in steel	assemble weir tray by welding
105	4	2" thread-a-let		
106	1	3" thread-a-let		
107	2	1" steel couplings		
108	2	2" steel couplings		
109	2	150# 8" slip-on flanges		
110	4	leg mounts	2x2x3/16 angle	weld to column
111	2	150# blind flange		
112	4	leg	2x2x3/16 angle	
113	4	pads for legs	8x8x1/4 plate	weld to legs
114	3	lifting lugs	1/4" plate	weld to column

NOTE: Shop not responsible for piping inside of column

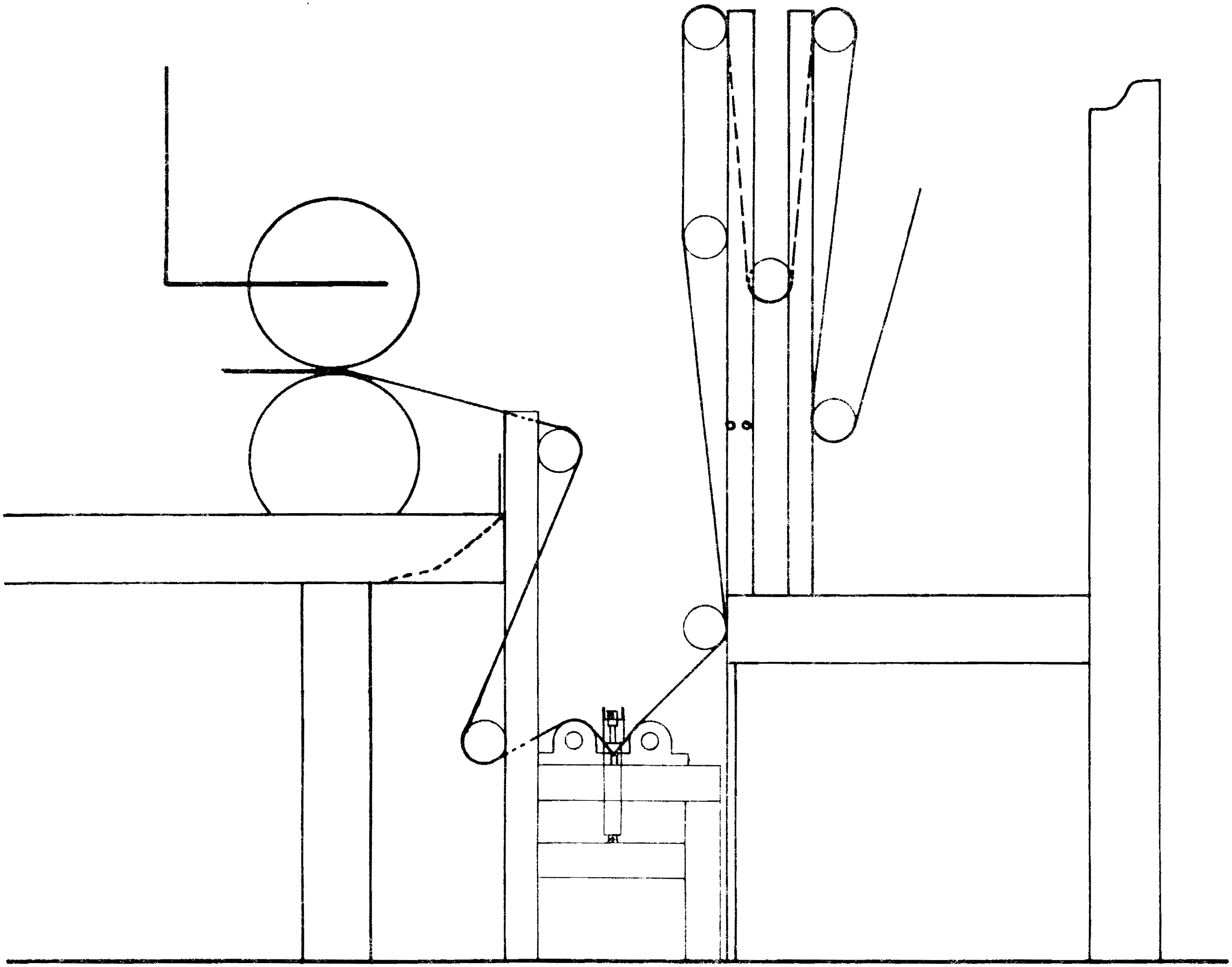


FIGURE I

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF TEXTILE ENGINEERING
ATLANTA, GEORGIA 30332
(404) 894-2490

January 6, 1981

Mr. David R. Klimaj
Department of Energy
Conservation and Solar Energy
Industrial Programs, CS-40
Forrestal Building
Washington, DC 20585

Subject: Contract No. DE-AS05-80CS40350
In-Plant Demonstration of a
Machnozzle as a Fabric Predrying
Device

Dear Mr. Klimaj:

The monthly Project Status Report for December 1980 for the subject contract is enclosed.

Please contact me in the event you have any questions regarding this report.

Sincerely,

W. W. Carr
Principal Investigator

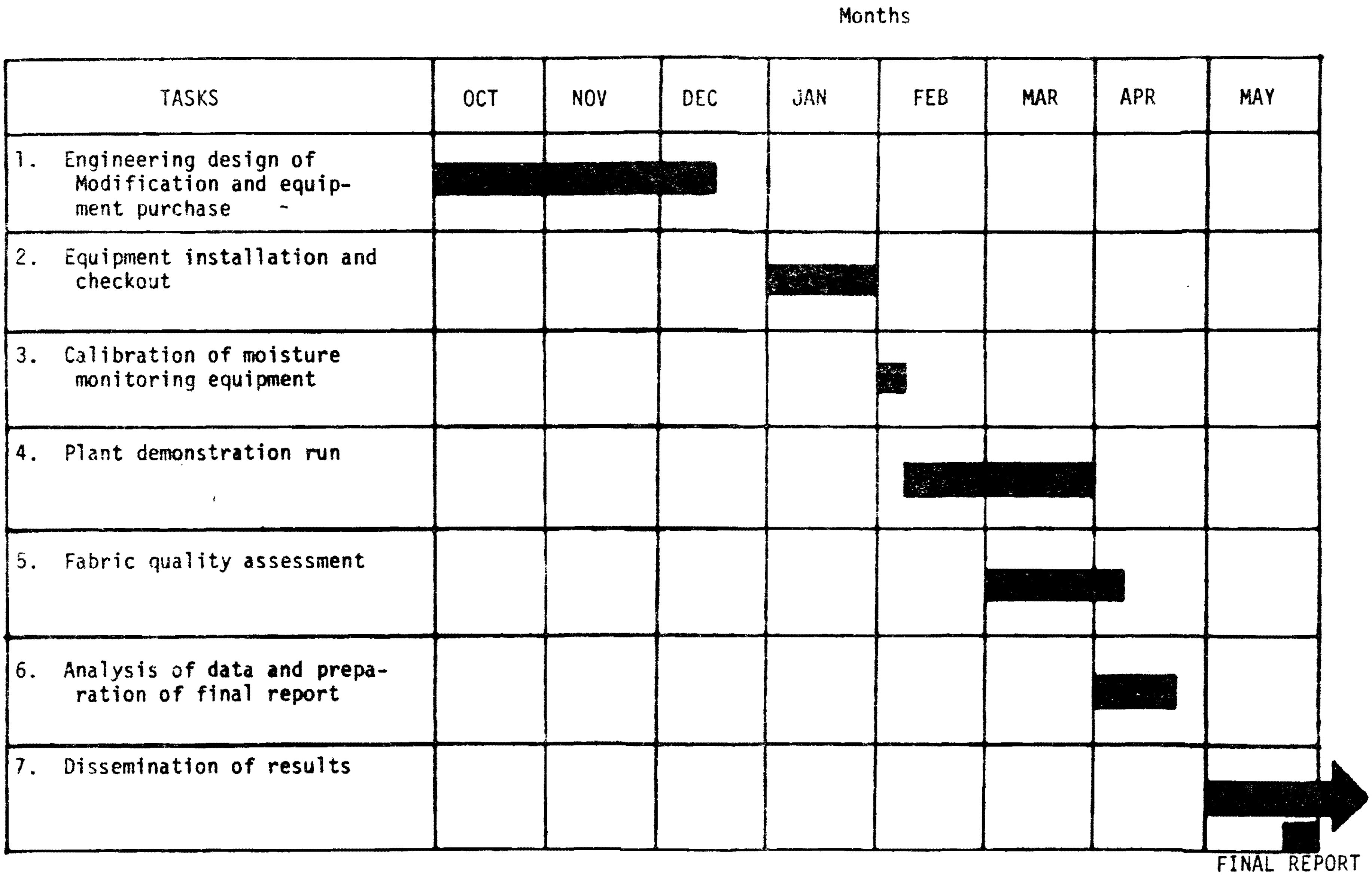
cc: Office of Contract Administration
Project File
W. D. Holcombe
W. C. Carter

Monthly Project Status Report - No. 3
In-Plant Demonstration of a Machnozzle
as a Fabric Predrying Device

Efforts during the month of December were directed at completing Task 1 (engineering design of modifications and equipment purchase). Specific accomplishments included:

- Construction of the condenser was begun and was nearing completion by the end of December. The condenser will be tested in January.
- Orifice plates and flanges were received and installed.
- Fixed steam flow monitoring equipment was ordered.
- Machnozzle fixture design was completed (shop drawing is enclosed).

As originally proposed, the duration of the machnozzle project was to be six months from start date of the project. However, the period of performance under the contract for the in-plant demonstration was nine months with a starting date of Septmeber 1, 1980, and expiration date of May 31, 1981. Although the contract starting date was September 1, 1980, the contract was not signed until September 25, 1980. Actual work on the project did not begin until October 1980. Our intentions have been to complete in-plant demonstration within six months as proposed. We have, however, experienced delays in procuring equipment necessary for the in-plant demonstrations. Specifically, difficulty in obtaining moisture monitoring equipment was encountered. Mahlo-American, Inc., located in Spartanburg, South Carolina, has agreed to supply moisture monitoring equipment for the in-plant demonstration by February 1, 1981. Our revised schedule of work is attached. The project will be completed before the expiration date of the contract.



Revised Schedule of Work 12/17/80

Monthly Project Status Report - No. 4
In-Plant Demonstration of a Machnozzle
As a Fabric Predrying Device

During January, preparation for the in-plant demonstration was continued. Accomplishments during the month included:

- Fabrication of condenser was completed, and tests were run. Test results indicated that the condenser is functioning properly.
- Fabrication of Machnozzle fixture and dummy ends was begun. Fabrication should be completed by the first week in February.
- Mounting fixture for moisture monitor was designed and materials for fixture was ordered.
- Orifice plates, flanges, and piping at J. P. Steven & Co., Inc., Delta #1 Plant were tested. Orifice plates were found to be oversized. New orifice plates were ordered.

Equipment set-up for the in-plant demonstration should be completed by the end of the second week of February. Start-up of the in-plant demonstration should occur during the third week of February.

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Monthly Project Status Report No. 5

// file

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF TEXTILE ENGINEERING
ATLANTA, GEORGIA 30332
(404) 894-2490

March 30, 1981

Mr. David R. Klimaj
Department of Energy
Conservation and Solar Energy
Industrial Programs, CS-40
Forrestal Building
Washington, DC 20585

Subject: Contract No. DE-AS05-80CS40350
In-Plant Demonstration of a
Machnozzle as a Fabric Predrying
Device

Dear Mr. Klimaj:

The monthly Project Status Report for February 1981 for the subject contract is enclosed.

Please contact me in the event you have any questions regarding this report.

Sincerely,

W. W. Carr
Principal Investigator

cc: Office of Contract Administration
Project File
W. D. Holcombe
W. C. Carter

During February, installation and check-out of equipment to be used during the in-plant demonstration were begun and completed. In-plant testing began on February 18, 1981.

Equipment installation and check-out included:

- o installation of machnozzle and accessory equipment (steam supply line, filter, control valves, guide rolls, air supply lines and valves for raising and lowering machnozzle, etc.)
- o installation and calibration of fixed steam flow monitoring equipment
- o installation of condenser system
- o installation and calibration of Mahlo's microwave-moisture-monitoring unit

On February 18, 1981, in-plant tests were begun. Preliminary tests were run to check the performance of the machnozzle. These tests were run using 65/33 polyester/cotton fabric (muslin weighing approximately 3.4 ounces per square yard). The steam supply pressure was approximately 90 psig, and the fabric process speed was approximately 115 YPM.

The results of the preliminary tests indicated that the 43.3-inch machnozzle was not reducing regain as effectively as the 16-inch machnozzle used in the laboratory tests. The regain measured after the machnozzle during the preliminary tests was approximately 41%. During laboratory tests of the same type fabric at a steam supply pressure of approximately 90 psig and a fabric speed of approximately 100 YPM, regain after the machnozzle was approximately 30%.

Two steps to reduce the regain after the machnozzle were taken. The first was to increase the steam supply pressure, and the second was to increase the machnozzle slot width. Although the steam pressure at the plant boiler room was 125 psig, the steam pressure at the machnozzle was only approximately 90 psig. The pressure difference apparently was due to the very long run of pipe between the machnozzle and the boiler. Several alternatives were discussed with plant personnel for increasing steam supply pressure. The plant opted to icrease the pressure at the boiler from 125 to 150 psig. The increase in pressure at the boiler resulted in the pressure at the machnozzle increasing from approximately 90 to approximately 105 psig. The increase in pressure was marginal and did not greatly affect regain.

The second step taken to reduce regain after the machnozzle involved increasing the slot in the machnozzle. The steam flow rate per linear inch of machnozzle was lower than that for the 16-inch machnozzle on which laboratory data was taken. By increasing the slot width, the flow rate was increased. A 0.002-inch shim was used to increase the slot width. With the 0.002-inch shim, regain after the machnozzle was 28%, which compared favorable with laboratory results. The steam flow rate per linear inch of machnozzle increased by approximately 15% over that for the no-shim condition. Since regain comparable to those obtained in the laboratory were obtained when the 0.002-inch shim was used, all of the succeeding tests were run using the 0.002-inch shim.

At the end of February, the machnozzle and accessory equipment was functioning properly. Plans were for the bulk of the test runs to be completed in March.

Monthly Project Status Report - No. 6
In-Plant Demonstration of a Machnozzle
As a Fabric Predrying Device

During March, the phase of the in-plant demonstration to be conducted by Georgia Tech personnel was substantially completed. No significant problems were encountered with the machnozzle, and preliminary analysis of the data indicates the machnozzle is a viable way of predrying sheeting-weight fabric.

Tests were run on five types of 43-inch, sheeting-weight goods. Each fabric was tested at two to four speeds. Machnozzle supply pressures of 20 psig to 115 psig were investigated. Also, the number of steam can stacks used was varied whenever possible. The tests are summarized in Table 1.

Although detailed analysis of the data is not available yet, preliminary analysis of the data has been made. The preliminary results indicate that the machnozzle can substantially reduce the regain in sheeting-weight fabric. The regain after the squeeze roll and just prior to the machnozzle was generally from 70 to 85%. Typically, the machnozzle reduced the regain of the fabric to approximately 20 to 35% at a steam supply pressure of 100 psig.

The energy requirements of the machnozzle compared favorable with those for steam cans. Typically the energy consumption of the machnozzle ranged from approximately 0.50 to 1.0 lb_s / lb_w (pounds of steam per pound of water removed) depending on process speed. The steam cans typically required from 1.5 to 2.3 lb_s / lb_w. The energy consumption data on the machnozzle given above are based on no energy recovered from the steam passing through the fabric. When the energy recovered by the condenser is considered, the machnozzle should be even more attractive as a device for predrying fabrics.

The condenser did not perform as well as hoped. The results of the condenser tests indicated that approximately 40% of the energy in the steam used by the machnozzle was being recovered. Since the savings were lowered than had been anticipated, the condenser has been redesigned. Further testing of the condenser is planned for April.

The second phase of the demonstration to be conducted by plant personnel has been delayed due to limited quantity of 43-inch-width fabric currently being processed. In the past, 43-inch-width fabric was used to produce pillow cases. Currently a new fabrication technique allows wider fabric to be used. As a result, the volume of 43-inch width fabric that is processed has decreased over the last few months.

Some 43-inch-width fabric is currently being processed; however, it it being processed almost exclusively on another drying range. Due to differences in the drying ranges, processing the narrower fabric on the drying range on which the machnozzle is located does not appear to be a viable alternative. The range on which the 43-inch-width fabric is being processed cannot process wider fabric that rescheduling would require.

The possibility of relocation the machnozzle and auxiliary equipment on the drying range that is processing the 43-inch-width fabric has been discussed with plant personnel. A decision on relocating the equipment has not been made yet.

Table 1 - Summary of Tests

Fabric Type	Process Speed (YPM)	Test Conditions
Textured 80/20 Polyester/cotton	50	Control - 1ST* Machnozzle - 1ST Pressures (psig)-30,40,60,80,100
	75	Control - 1ST, 2ST, 3ST, and 4ST Machnozzle - 1ST Pressures (psig)-20,40,60,80,100 and 110
	100	Control 2ST, 3ST, 4ST Machnozzle - 1ST Pressures (psig) -20,40,60,80,100
	125	Control 2ST Machnozzle - 1ST Pressures (psig)-60,80,100
Muslin 65/35 Polyester/Cotton	75	Control - 2ST and 4ST Machnozzle 1 ST Pressures (psig)-40,60,80,100 2ST Pressures (psig)-100
	100	Control - 2ST, 3ST and 4ST Machnozzle - 1ST Pressure (psig)-20,40,60,80, and 100
	115	Control-2ST, 3ST and 4ST Machnozzle - 2ST Pressure (psig)-20,40,60,80 and 100
	115**	Control - 2ST, 3ST and 4ST Machnozzle - 2ST Pressures (psig) 103 to 110

*ST refers to a stack of ten steam cans
1ST means that one stack of cans was used during test,
2ST means that two stacks of cans were used during test, etc.
**No Shim in Machnozzle

Fabric Type	Process Speed (YPM)	Test Conditions
Percale 65/35 Polyester/cotton	50	Control - 2ST Machnozzle - 2ST Pressures (psig) 80
	75	Control 2ST, 3ST, and 4ST Machnozzle - 1ST Pressures (psig) 20,40,60,80 100 and 115
100% Cotton	70	Control* 0 ST Machnozzle 0 ST Pressures (psig) 40,60,80,100 and 110
Percale 50/50 Polyester/cotton	50	Control - 1ST and 4ST Machnozzle - 1ST Pressure (psig)-40,60,80, and 100
	75	Control - 1ST, 2ST, 3ST and 4ST Machnozzle - 1ST Pressures (psig) - 80 and 95
*	80	Control - 1ST Machnozzle - 1ST Pressures (psig)-40,60,80, and 95
*	100	Control 1ST and 4S Machnozzle - 1ST and 4ST Pressures (psig)-60,80,90

*Rerun fabric

Monthly Project Status Report - No. 7
In-Plant Demonstration of a Machnozzle
As A Fabric Predrying Device

Efforts during the month of April were directed at the following tasks:

- Modifying and testing condenser
- Analyzing data from in-plant demonstrations
- Assessing fabric quality

The results of initial condenser tests indicated that approximately 40% of the thermal energy in the steam used by the machnozzle was recovered. Since the recovery was lower than had been anticipated, the condenser was redesigned. The weir tray that had been used to introduce water into the condenser column was replaced with spray nozzles. Several condenser tests were conducted during April. Depending on test conditions, thermal energy recovery (in the form of hot water) ranged from 60 to 70%.

The data taken during the in-plant demonstration have been analyzed. The primary parameters considered were fabric type, fabric speed, and Machnozzle supply pressure. Test results show that the Machnozzle can substantially reduce the moisture in sheet-weight fabrics.

The wet pick-up after the squeeze roll and just prior to the Machnozzle was approximately 70 to 85%. Figures 1-4 show the effect of the Machnozzle on the wet pickup in four common sheeting-weight fabrics. Typically, when the Machnozzle is operating at a steam supply pressure of 100 psig, the wet pick-up of the fabric is reduced to approximately 20 to 35% at a steam supply pressure of 100 psig.

The effects of fabric speed and steam supply pressure on the moisture removal capability of the Machnozzle can be seen in Figures 1-4. Typically as steam supply pressure is increased, wet pick up of the fabric after passing over the Machnozzle is reduced. However, as steam supply pressure is increased, steam consumption of the Machnozzle also is increased. Thus, operation at maximum obtainable pressure may not necessarily be the most energy-efficient manner to run the Machnozzle. As fabric speed is increased, the wet pickup in the fabric after passing over the Machnozzle increased slightly.

However, the quantity of water removed by the machnozzle in a given time increases since the Machnozzle processes more fabric per unit time. Since the steam consumption of the Machnozzle varies little with fabric speed, the Machnozzle is more energy-efficient at higher fabric speeds.

In Figures 5-8, the energy requirements of the Machnozzle are compared with those for steam cans. The energy consumption of the Machnozzle is substantially lower than that of steam cans. Typically the energy consumption of the Machnozzle ranged from approximately 0.50 to 1.0 lb_s/lb_w (pounds of steam per pound of water removed) depending on process speed. The steam cans typically required from 1.5 to 2.3 lb_s/lb_w. The energy consumption data of the Machnozzle shown in Figures 5-8 are based on no energy recovered from the steam passing through the fabric. When an energy recovery factor of 65% is applied to the data, the energy consumption of the Machnozzle ranges from approximately 0.18 to 0.35 lb_s/lb_w.

Steam can data for 2, 3, and 4 stacks are shown in Figures 5-8. Under normal operating conditions, the plant utilizes four stacks of cans. During the demonstration, it was determined that the fabric was bone dry after two stacks of cans. Therefore utilization of the last two stacks of cans was unnecessary and energy wasteful. In many cases, a 20 to 30% reduction in energy consumption for predrying could be obtained simply by turning off stacks of steam cans.

Tests to assess the effect of the Machnozzle on fabric quality were begun in April.

FIGURE 1

80/20 POLYESTER/COTTON TEXTURED
2.94 oz/yd^2

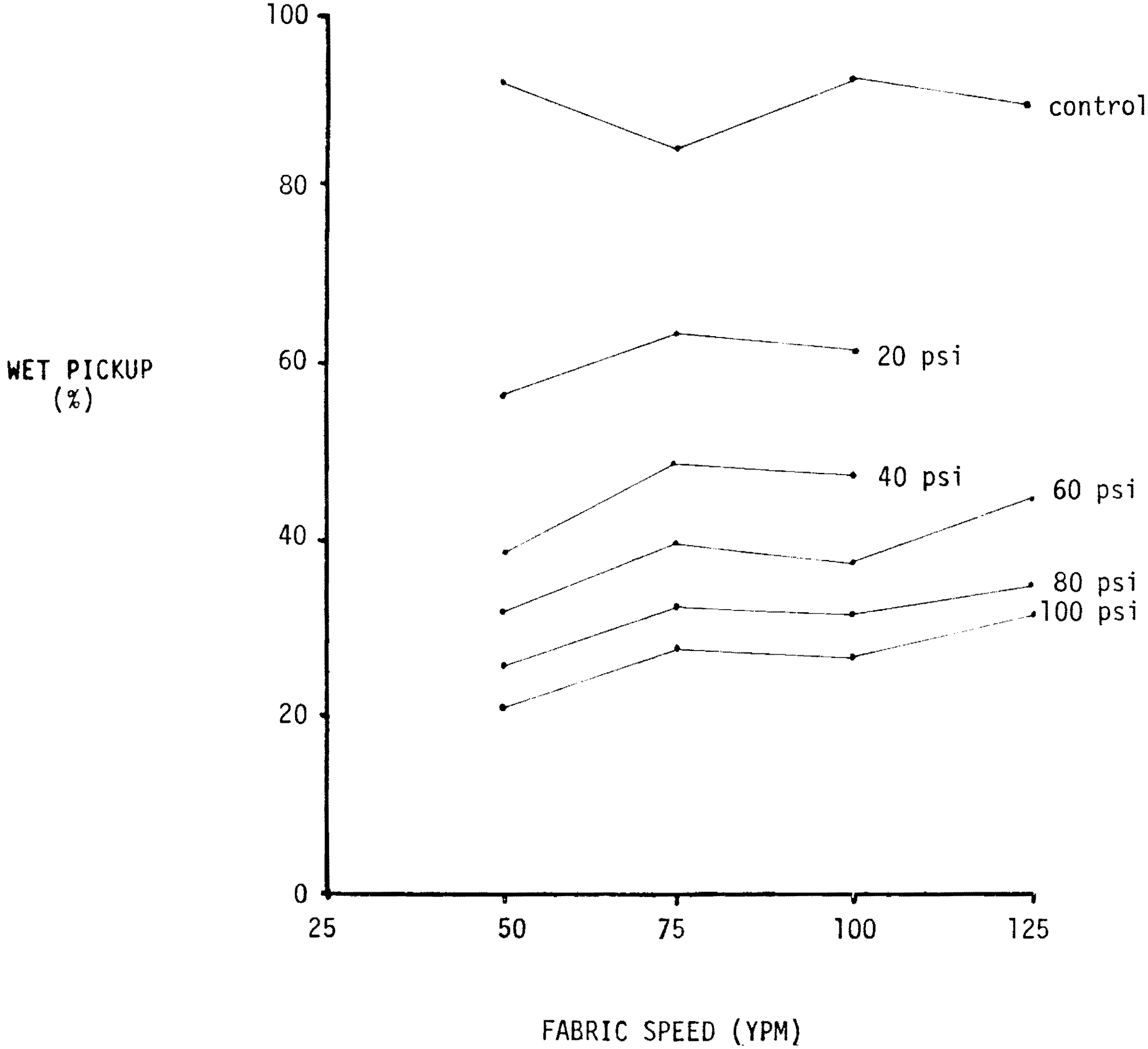


FIGURE 2

65/35 POLYESTER/COTTON MUSLIN

3.42 oz/yd^2

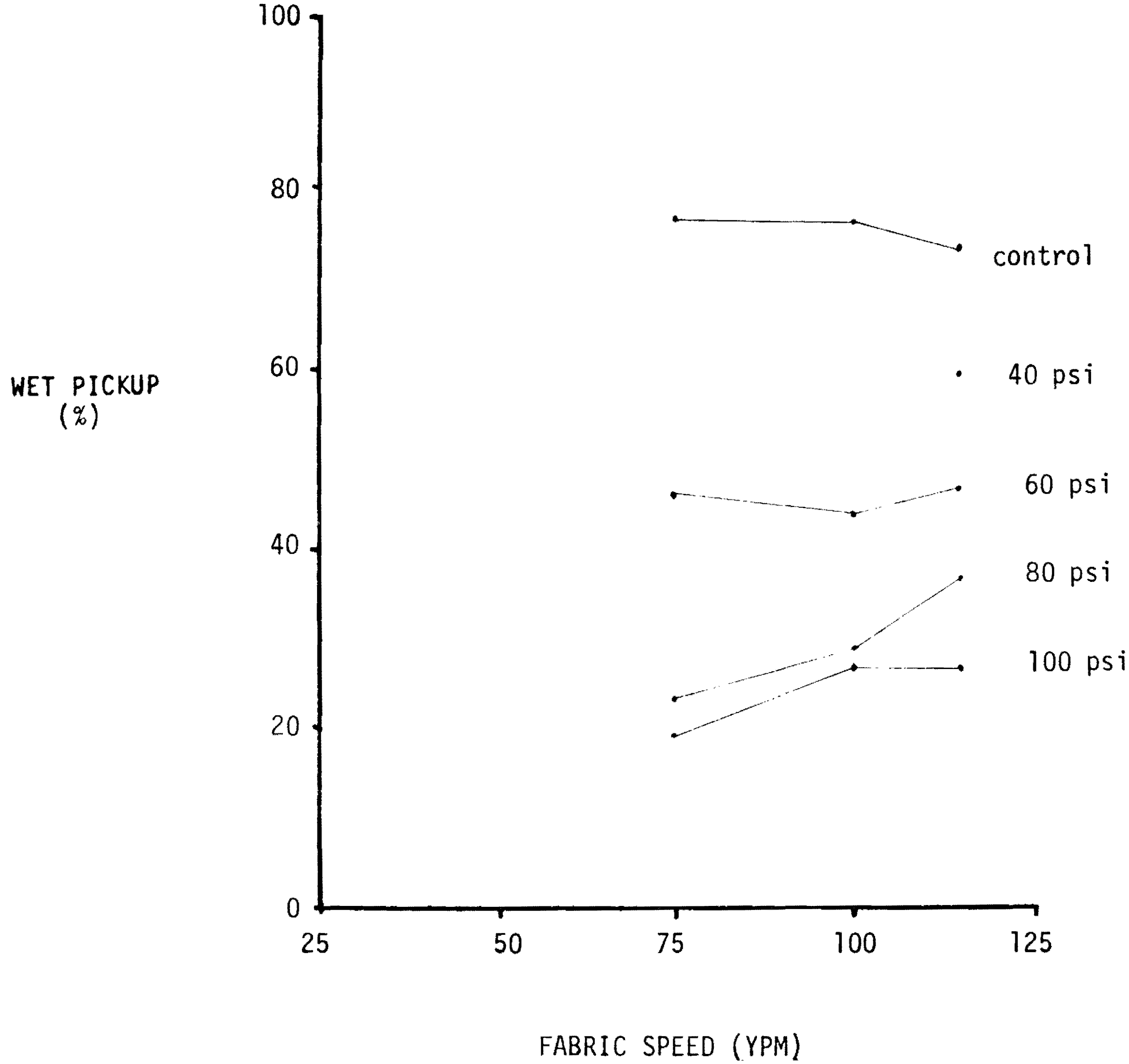


FIGURE 3

65/35 POLYESTER/COTTON PERCALE
3.41 oz/yd^2

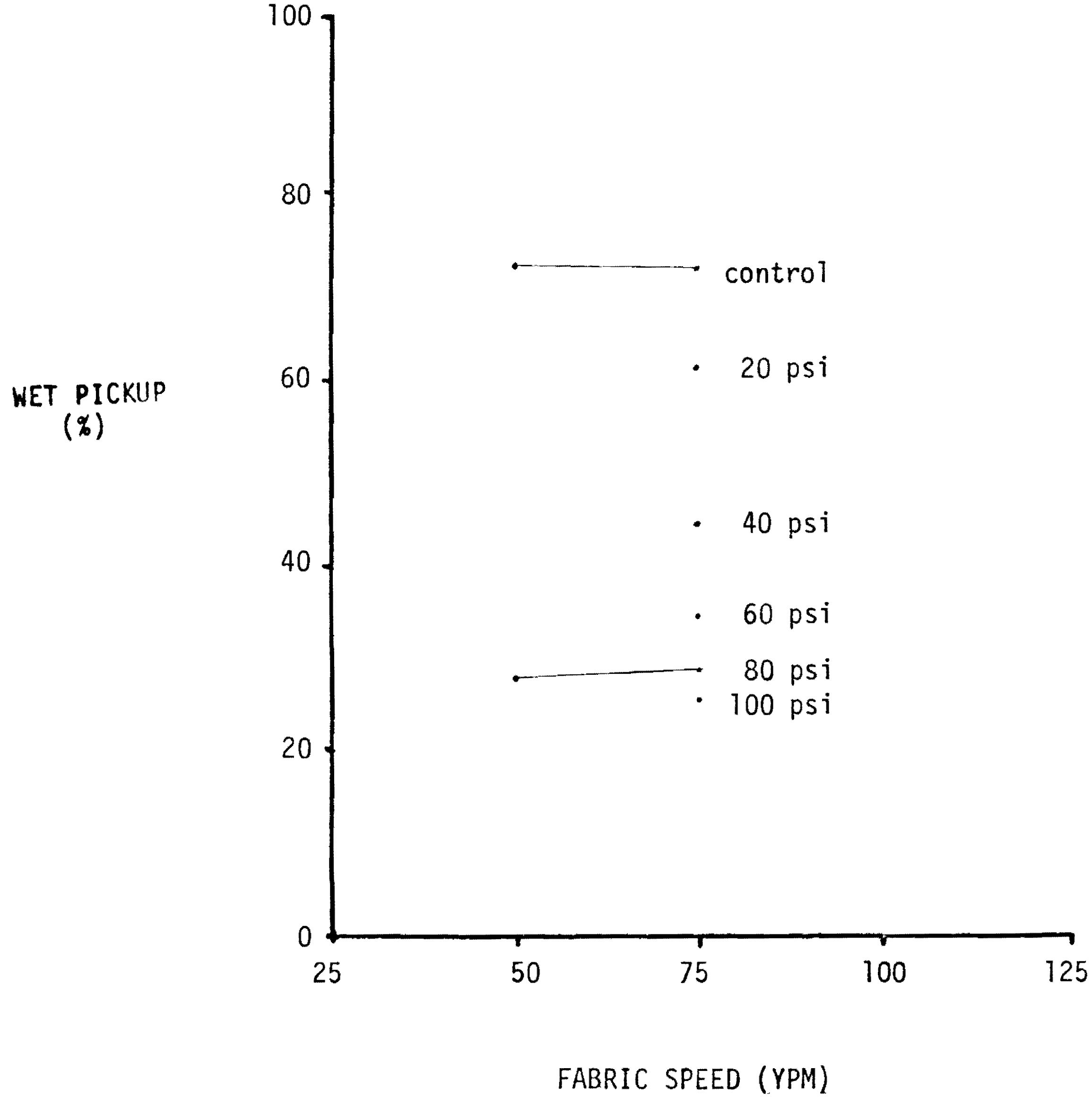


FIGURE 4

50/50 POLYESTER/COTTON PERCALE

3.40 oz/yd^2

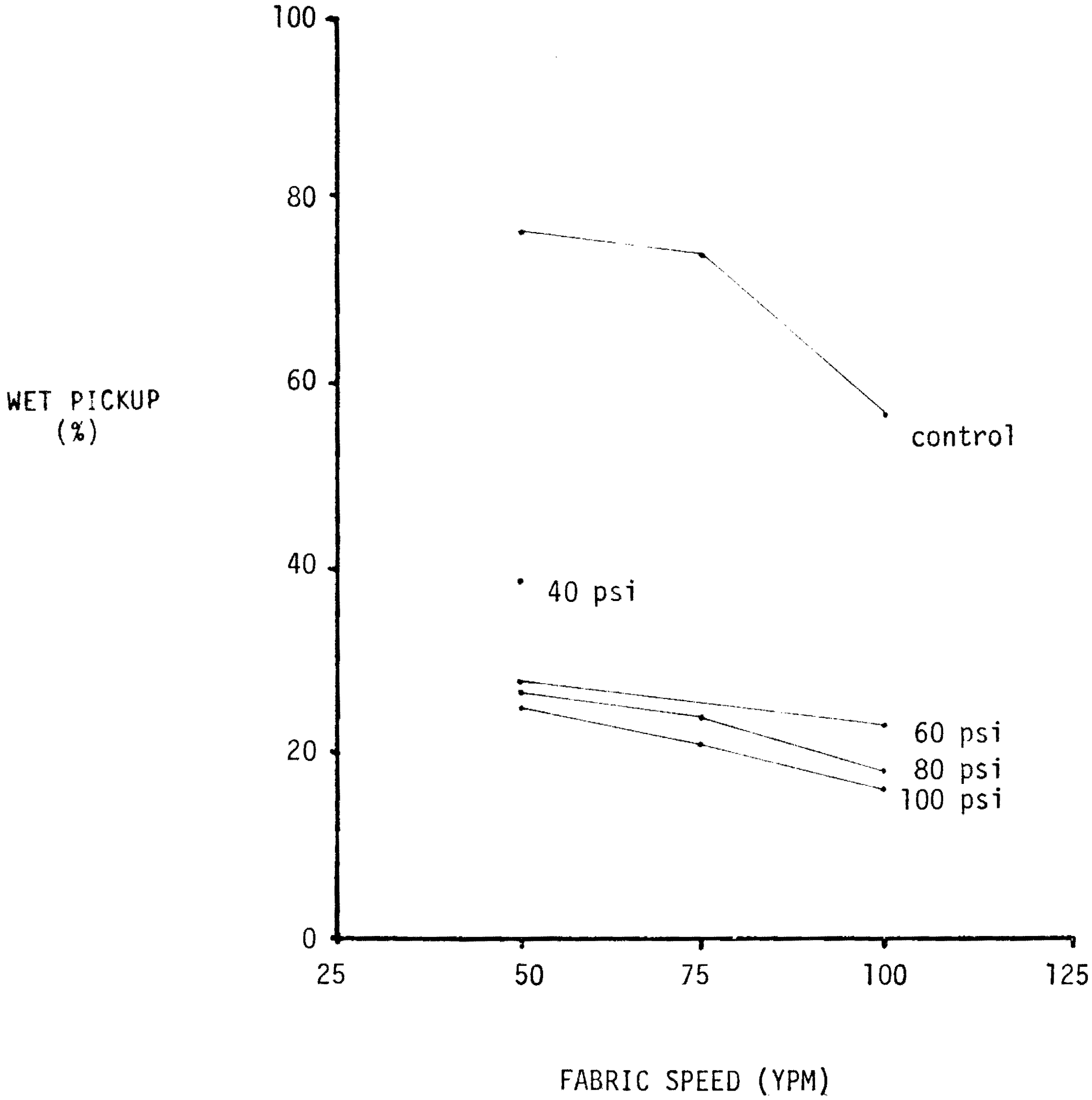


FIGURE 5
80/20 POLYESTER/COTTON TEXTURED
2.94 oz/yd^2

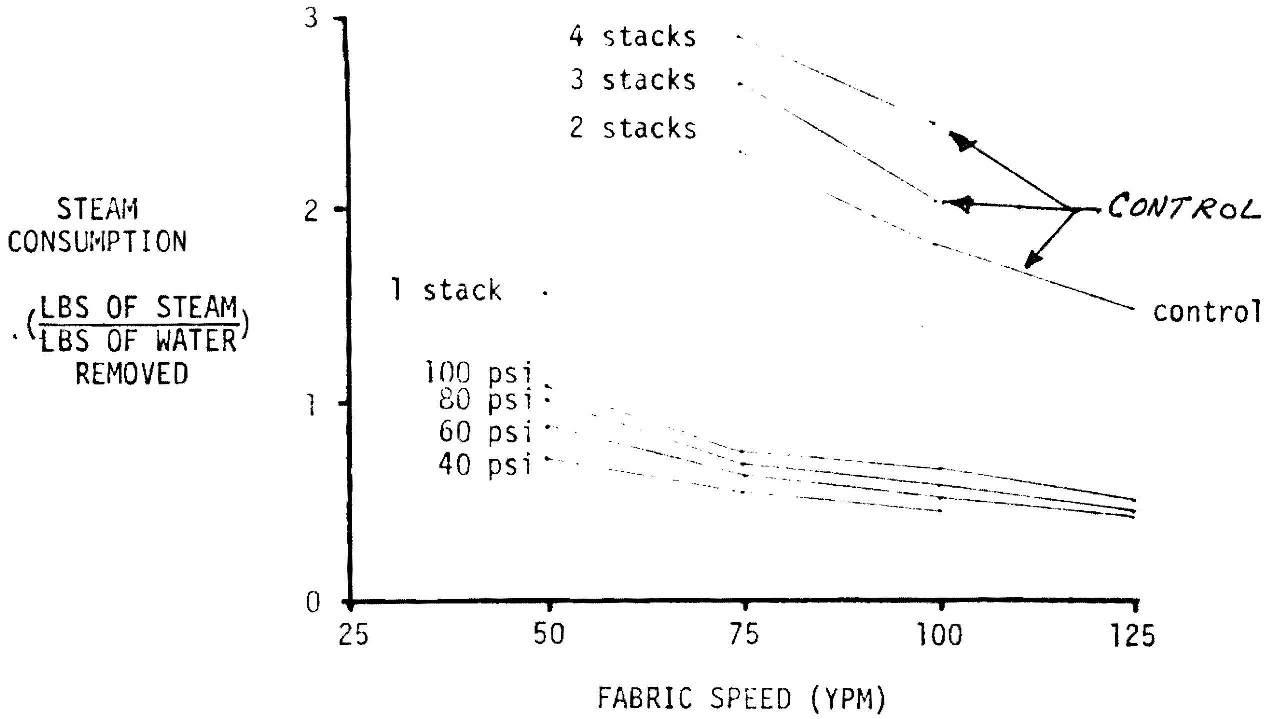


FIGURE 6

65/35 POLYESTER/COTTON MUSLIN
$3.42/oz/yd^2$

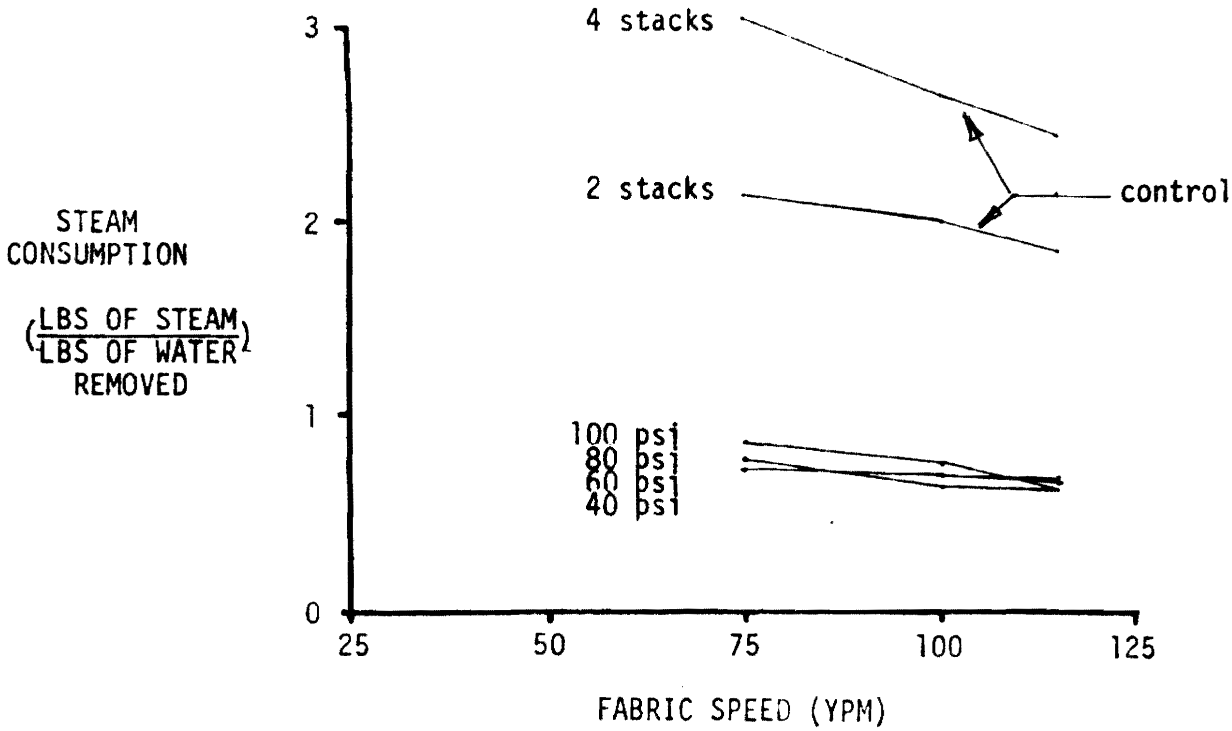


FIGURE 7

65/35 POLYESTER/COTTON PERCALE
3.41 oz/yd^2

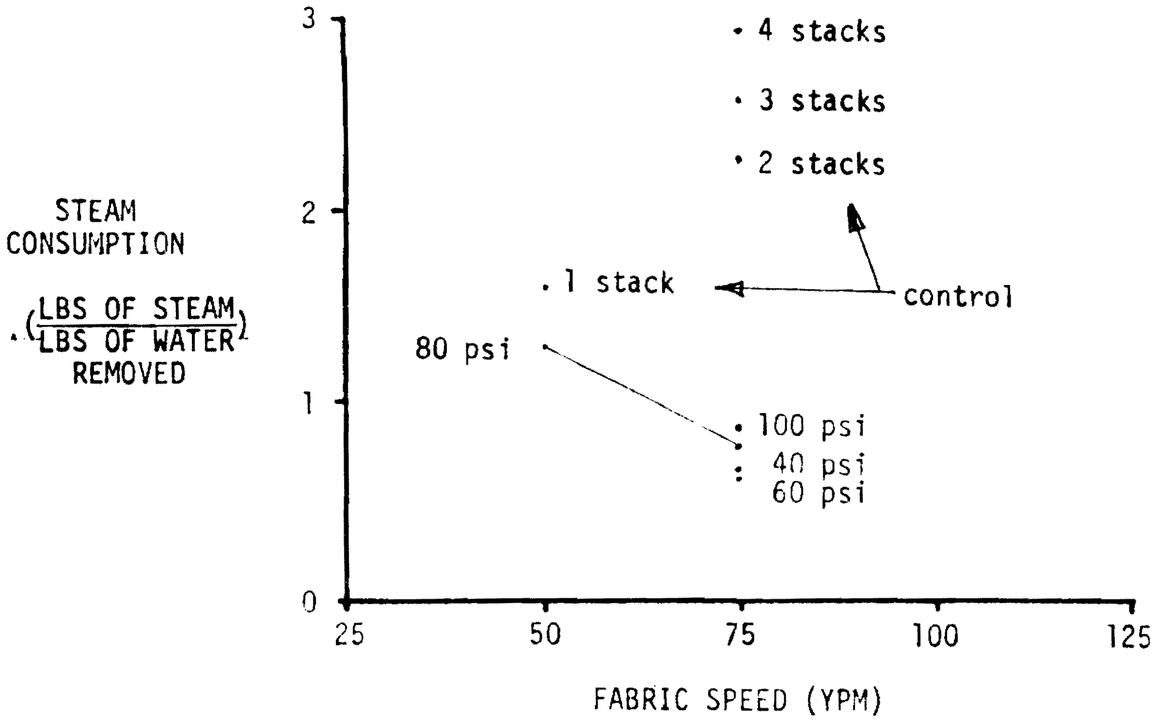
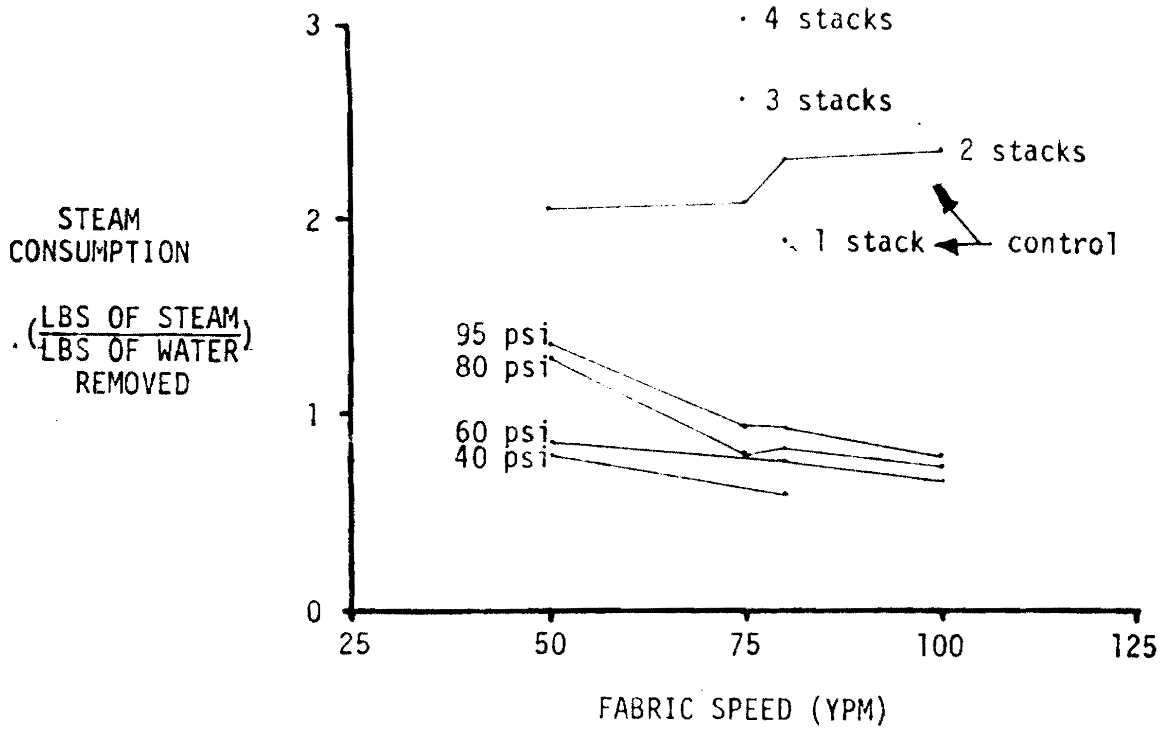


FIGURE 8

50/50 POLYESTER/COTTON PERCALE
3.40 oz/yd²



U.S. DEPARTMENT OF ENERGY

FORM DOE 536 (1/78)

CONTRACT MANAGEMENT SUMMARY REPORT

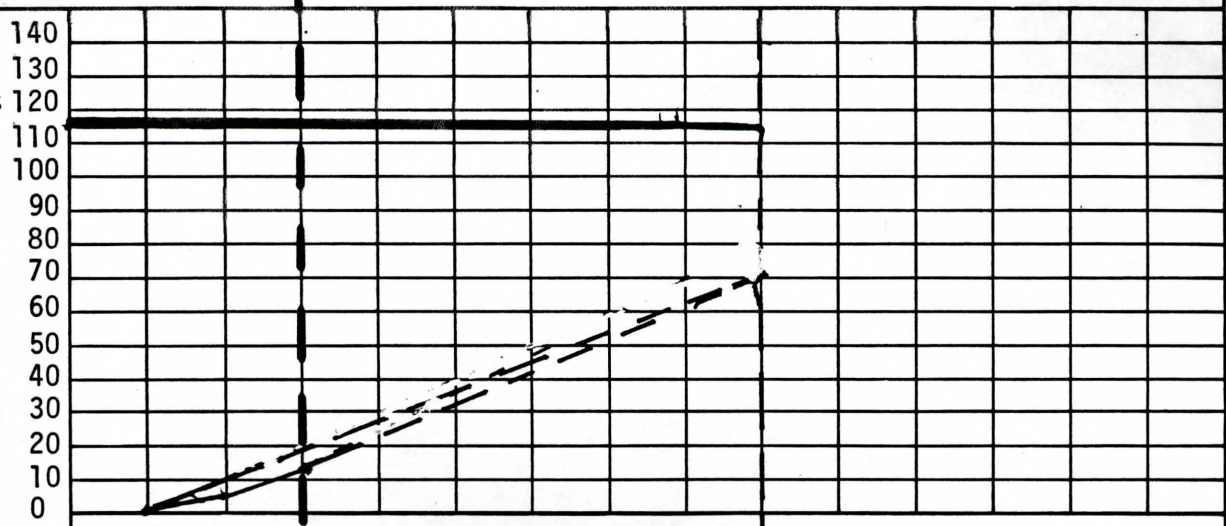
FORM APPROVED
OMB NO. 38R–0190

1. Contract Identification In-Plant Demonstration of a Machnozzle as a Fabric Predrying Device	2. Reporting Period 9/1/80 through 11/30/80	3. Contract Number DE-AS05-80C54350
4. Contractor (Name and Address) Georgia Tech Research Institute Georgia Institute of Technology Atlanta, Georgia 30332		5. Contract Start Date 9/1/80
		6. Contract Completion Date 5/31/81

7. Months	S	O	N	D	J	F	M	A	M						8. FY 81

9. Cost Status

a. Thousands of Dollars



b. B&R Numbers

g. Cost Plan Date 10/01/80

h. Planned Costs Prior FYs NA

i. Actual Costs Prior FYs NA

j. Total Estimated Costs for Contract 69,352

k. Total Contract Value 69,352

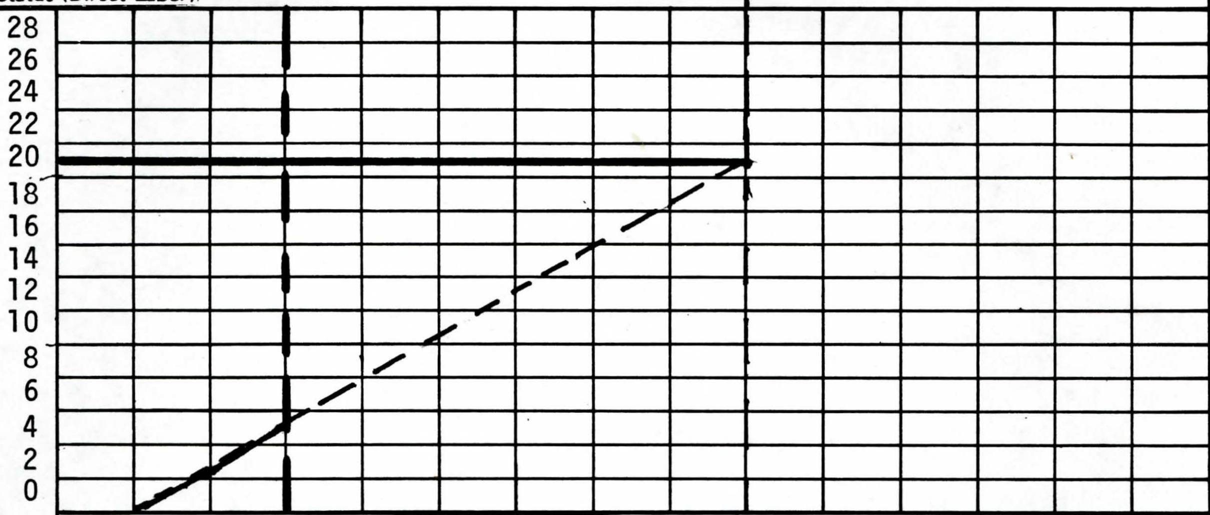
l. Unfilled Orders Outstanding 2,880

Accrued Costs		S	O	N	D	J	F	M	A	M						
	c. Planned	0	8.669	8.669	8.669	8.669	8.669	8.669	8.669	8.669						
	d. Actual	0	5.876													
	e. Variance	0	2.793													
	f. Cum. Variance	0	2.793													

m. Estimate for Subsequent Reporting Period 34,773

10. Manpower Status (Direct Labor)

a. Hundreds of Manhours



e. Manpower Plan Date 10-01-80

f. Planned Manpower Prior FYs N/A

g. Actual Manpower Prior FYs N/A

h. Total Estimated Manpower for Contract 20,973

i. Total Contract Manpower 20,973

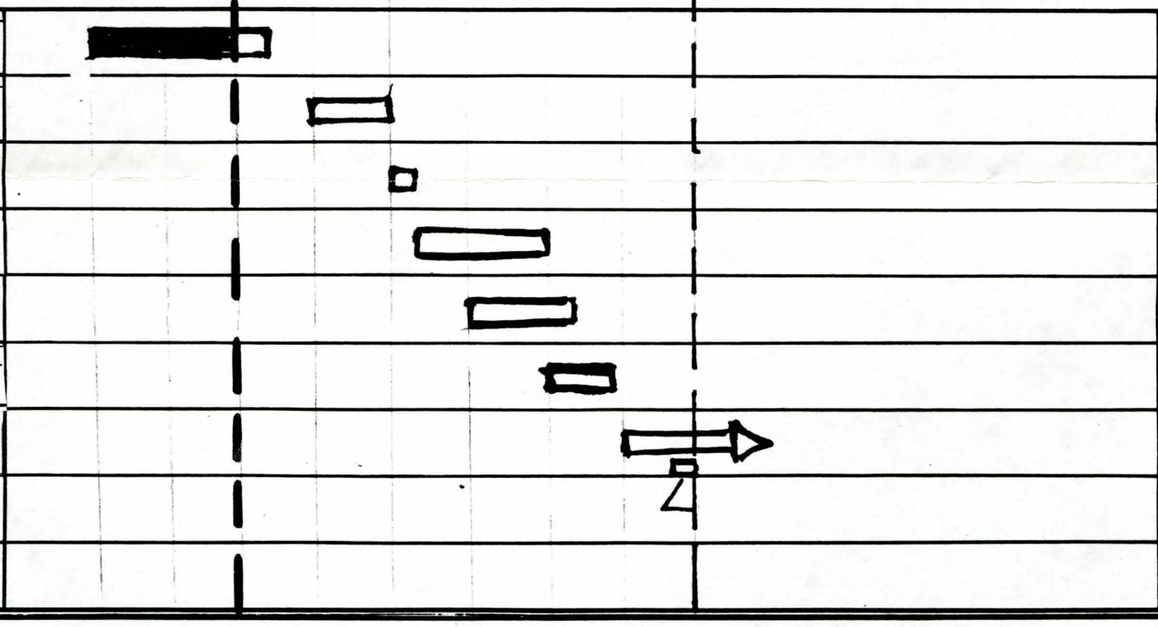
Manpower		S	O	N	D	J	F	M	A	M						
	b. Planned	0	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62						
	c. Actual	0	2.57	2.61												
	d. Variance		0.05	0.07												

11. Major Milestone Status

1. Engineering design of modification and equipment purchase
2. Equipment installation and checkout
3. Calibration of moisture monitoring equipment
4. Plant demonstration run
5. Fabric quality assessment
6. Analysis of data and preparation of final report
7. Dissemination of results

h.

i.



12. Remarks

13. Signature of Contractor's Project Manager and Date

14. Signature of Government Technical Representative and Date

CONTRACT MANAGEMENT SUMMARY REPORT

PURPOSE

A single-page graphic presentation of integrated cost, manpower, and schedule for rapid visual analysis and trend forecasting.

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f – Enter the cumulative variance by month. Show minus amounts in parentheses.

g – Enter the date of the current approved cost plan.

h – Enter total planned costs for all prior fiscal years (see latest approved Cost Plan, Item 8).

i – Enter total actual costs for all prior fiscal years (see latest approved Cost Plan, Item 9).

j – Enter the current estimate of total costs required for the contract. This includes prior year actuals, current fiscal year actuals to date, plus the contractor's estimate of funds required to complete the remaining work of the contract.

k – Enter total negotiated contract cost.

l – Enter the actual value of committed but unfilled orders outstanding to date. (This figure should be identical to Item 21 of the Cost Management Report.)

m – Enter the current estimated cost for the subsequent reporting period.

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b – Enter total planned manpower for each month indicated in Item 7.

c – Enter total actual manpower for each month up to and including the month being reported.

d – Subtract the actual manpower (10c) from the planned manpower (10b) and enter the difference. Show minus amounts in parentheses.

e – Enter the date for the latest approved manpower plan.

f – Enter total planned manpower for all prior fiscal years.

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h – Enter current estimate of total manpower required to complete the contract. This includes actuals for prior fiscal years, the current fiscal year actuals to date, plus the contractor's best estimate of manpower required to complete the remaining work on the contract.

i – Enter total negotiated contract manpower.

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– Enter event identifiers as established in contract. In the space to the right of each event, plot milestone and activity data by month. If an event is not scheduled for completion in the time period shown on the form, enter in the space at the extreme right the planned month and the year of completion.

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Item 14 – Signature of DOE Government Technical Representative and date indicating the GTR has reviewed the report. The signature does not constitute a certification of the accuracy of the report nor does it constitute any agreement with the contents of the report, or commit the Government in any way.

CHARTING INFORMATION

SYMBOLS

△ Major Milestone

● Major Milestone on the Project Critical Path

▽ Intermediate Event (Deliverable, Supporting Milestone, or Decision Point)

▲ Intermediate Event completed early or late

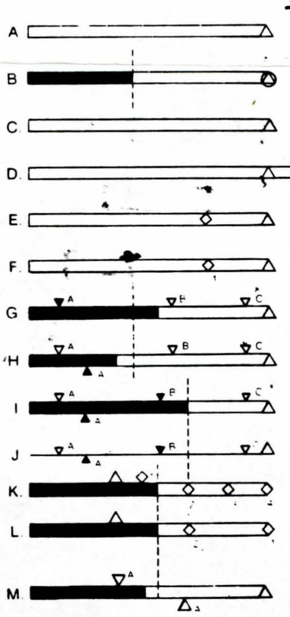
◇ Proposed Scheduled Deviation (late or early) for a Major Milestone

Activity Bar

Time Line

Time Now

EXAMPLES



A Major milestone with an activity bar

B Time now and work done, event on critical path

C ◇ Schedule Deviation (not yet approved)

D First change approved (slippage)

E Improvement, not contractually implemented

F First change approved (improvement)

G Activity ahead of schedule

H Activity behind schedule

I Late and on time completion of intermediate events A and B, respectively

J Same as Example I, above except that here a time line is used in place of an activity bar

K Original major milestone date and four subsequent approved changes (all slippages) to that date

L Original major milestone date and two subsequent approved changes (one slippage, one improvement to that date)

M Intermediate event schedule deviation

*U.S. GOVERNMENT PRINTING OFFICE: 1978--281-130/ 518

FORM DOE 536
(1/78)

U.S. DEPARTMENT OF ENERGY

CONTRACT MANAGEMENT SUMMARY REPORT

FORM APPROVED
OMB NO. 38R–0190

1. Contract Identification: In-Plant Demonstration of a Machnozzle as a Fabric Predrying Device

2. Reporting Period: 12/1/80 through 02/28/81

3. Contract Number: DE-AS05-80C54350

4. Contractor (Name and Address):
Georgia Tech Research Institute
Georgia Institute of Technology
Atlanta, Georgia 30332

5. Contract Start Date: 9/1/80

6. Contract Completion Date: 5/31/81

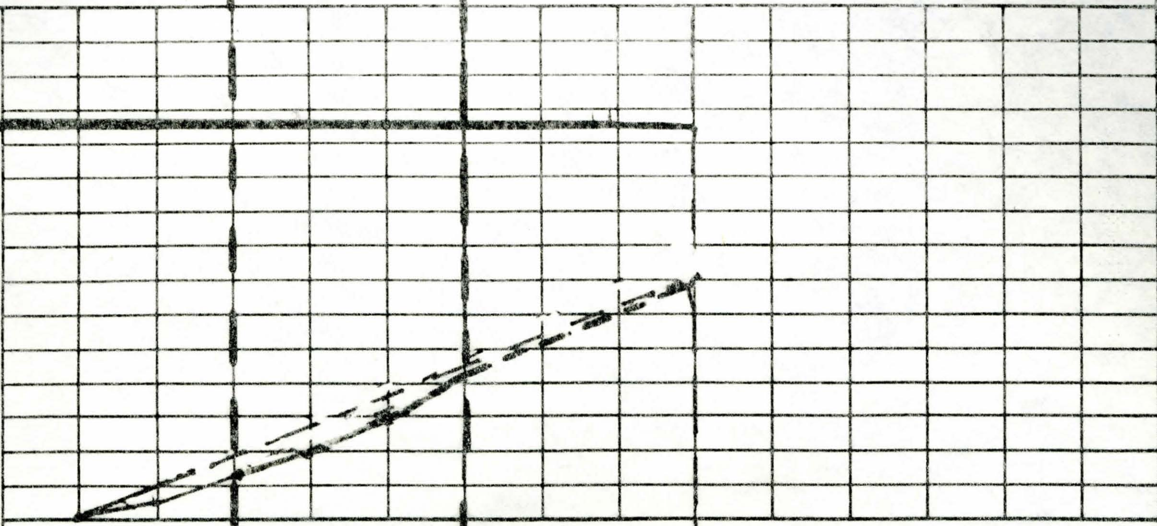
7. Months: S O N D J F M A M

8. FY 81

9. Cost Status

a. Thousands of Dollars (0–140)

b. B&R Numbers



Accrued Costs	S	O	N	D	J	F	M	A	M
c. Planned	0	8.669	8.669	8.669	8.669	8.669	8.669	8.669	8.669
d. Actual	0	5.876	5.522	7.427	10.389	11.416			
e. Variance	0	2.793	3.147	1.242	(1.720)	(2.747)			
f. Cum. Variance	0	2.793	5.940	7.182	5.462	2.715			

g. Cost Plan Date: 10/01/80

h. Planned Costs Prior FYs: NA

i. Actual Costs Prior FYs: NA

j. Total Estimated Costs for Contract: 69,352

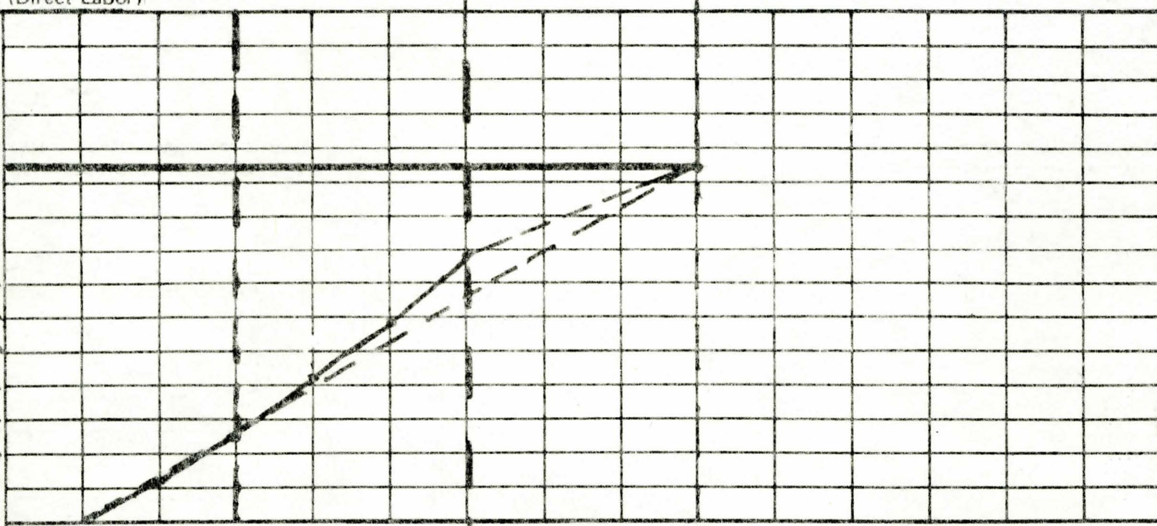
k. Total Contract Value: 69,352

l. Unfilled Orders Outstanding: 2,880

m. Estimate for Subsequent Reporting Period: 34,773

10. Manpower Status (Direct Labor)

a. Hundreds of Manhours (0–28)



Manpower	S	O	N	D	J	F	M	A	M
b. Planned	0	2.62	2.62	2.62	2.62	2.62	2.62	2.62	2.62
c. Actual	0	2.57	2.61	3.36	3.21	3.91			
d. Variance		0.05	0.07	(0.74)	(0.59)	(1.29)			

e. Manpower Plan Date: 10-01-80

f. Planned Manpower Prior FYs: N/A

g. Actual Manpower Prior FYs: N/A

h. Total Estimated Manpower for Contract: 20,973

i. Total Contract Manpower: 20,973

11. Major Milestone Status

1. Engineering design of Modification and equipment purchase
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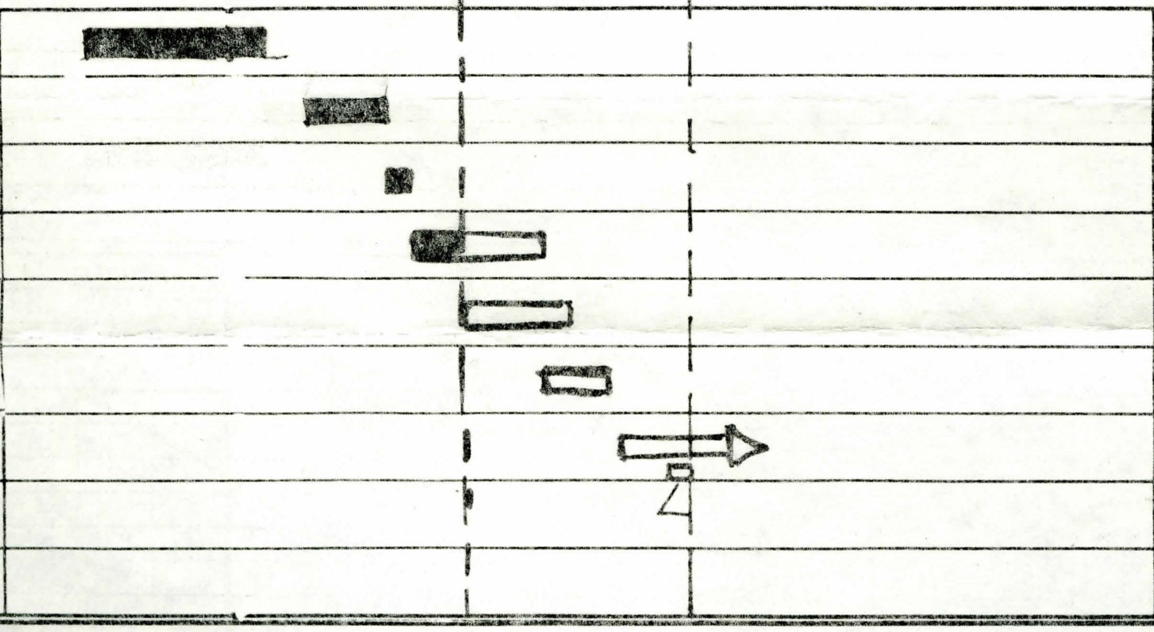

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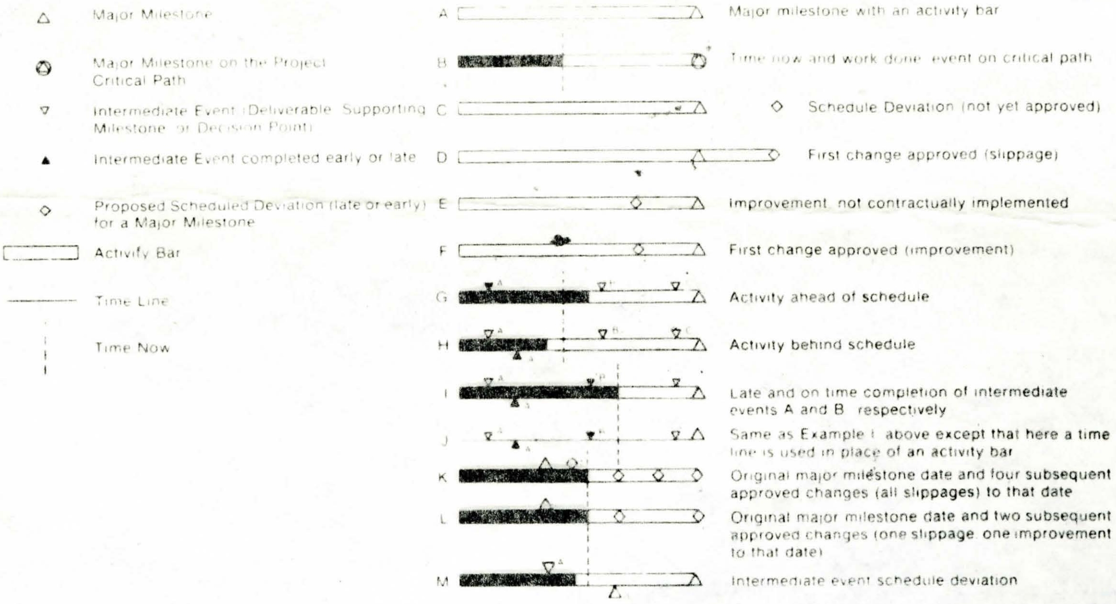

☆ U.S. GOVERNMENT PRINTING OFFICE: 1978--281-130/ 518

FINAL REPORT

IN–PLANT DEMONSTRATION OF A MACHNOZZLE AS A FABRIC PREDRYING DEVICE

Investigators:

W. W. Carr
W. D. Holcombe
S. D. Robertson
W. C. Carter

Prepared by

Engineering Experiment Station
and
School of Textile Engineering
GEORGIA INSTITUTE OF TECHNOLOGY

Prepared for

U.S. DEPARTMENT OF ENERGY
Assistant Secretary for Conservation and Solar Energy
Office of Industrial Programs

October 1981

GEORGIA INSTITUTE OF TECHNOLOGY
A Unit of the University System of Georgia
Engineering Experiment Station
Atlanta, Georgia 30332

1981

IN-PLANT DEMONSTRATION OF A MACHNOZZLE AS A FABRIC PREDRYING DEVICE

Final Report
October 12, 1981

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DISCLAIMER

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ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support extended to the project by the J.P. Stevens and Co., Inc. Research and Development and Delta #1 plant management and staff. Special appreciation is due to the following individuals:

F.X. Werber, Vice President, Research and Development

I.E. Pensa, Director of Chemicals and Process Development, Research and Development

R.L. Gill, Finishing Plant Manager, Delta #1 Plant

M.F. Wynn, Quality Control Supervisor, Delta #1 Plant

E.C. Mosley, Project Coordinator, Delta #1 Plant

W.R. Burnett, Corporate Engineer, Delta #1 Plant

M.W. Presley, Finishing Plant Engineer, Delta #1 Plant

Dr. I.E. Pensa was responsible for J.P. Stevens and Co., Inc.'s initial interest in the project. He played an important role in having the project approved and in obtaining a plant site for the demonstration. Those efforts and Pensa's guidance and support during the demonstration are gratefully acknowledged.

The authors express their thanks to Mr. Clayton Mosley for acting as project coordinator. His patience, attention, and time spent in handling details of the project contributed greatly to the success and timely completion of the project.

Thanks are extended to Ms. Kathy Pearson, co-operative plan student. Ms. Pearson carried out many of the necessary details throughout the course of the project. Ms. Deborah Morris is recognized for the typing and assembling of the report.

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SUMMARY

The Georgia Institute of Technology Engineering Experiment Station and School of Textile Engineering, along with J.P. Stevens and Co., Inc. have demonstrated on a commercial scale, a Machnozzle as a predrying device for fabrics. The project was sponsored jointly by the Department of Energy and J.P. Stevens and Co., Inc. and followed up a pilot-scale demonstration of a Machnozzle as a predrying device performed under a previous Department of Energy contract.

A 43.3-inch Machnozzle was installed on a continuous finishing range at the J.P. Stevens and Co., Inc. Delta #1 plant in Clemson, South Carolina. A condenser was designed and installed to recover the exhaust steam from the Machnozzle. The steam flows to the Machnozzle and steam cans were measured with orifice plates and differential pressure sensing devices, and the fabric regain was monitored with a Mahlo microwave moisture monitor.

Experimental tests were conducted on five types of 43-inch, sheeting-weight fabrics. Each fabric was tested at two to four speeds. Machnozzle steam supply pressures of 20 to 115 psig were investigated, and the number of can stacks in use was varied.

The results of the in-plant demonstration showed that the Machnozzle can substantially reduce the regain in sheeting-weight fabrics. The regain after the squeeze roll and just prior to the Machnozzle generally ranged from 70 to 85%. Typically, the Machnozzle reduced the regain of the fabric to approximately 20% to 35% at a steam supply pressure of 100 psig.

The reduction in regain obtained with the Machnozzle depended on fabric speed and steam supply pressure. For the range of parameters investigated, the effect of steam supply pressure was greater than that of fabric speed. For example, the regain of 80/20 textured polyester/cotton fabric (2.92 ounces per square yard) processed at 50 YPM was reduced to 57, 39, 32, 26, and 21% for steam supply pressures of 20, 40, 60, 80, and 100 psig, respectively. When fabric speed was increased to 100 YPM, the regain was reduced to 62, 48, 38, 32, and 27% for steam supply pressures of 20, 40,

60, 80 and 100 psig, respectively.

The energy requirements of the Machnozzle compared favorably with those for steam cans. Typically the energy consumption of the Machnozzle ranged from approximately 0.5 to 1.1 lbs/lbw (pounds of steam per pound of water removed) depending on process speed. The steam cans typically required from 1.5 to 3.3 lbs/lbw. The energy data on the Machnozzle given above were based on no energy recovered from the steam passing through the fabric. Energy recovery tests indicated that 60 to 70% of the thermal energy of the steam entering the Machnozzle can be recovered. Assuming a 65% recovery, the steam requirements to predry fabrics with the Machnozzle ranged from 0.2 to 0.4 lbs/lbw.

Tests were made on fabric samples to determine whether the properties of fabrics processed by the Machnozzle differed from those of conventionally processed fabrics. Fabric samples were tested for color, air permeability, and pilling. In addition, the fabrics were examined microscopically. All of the tests indicated that the Machnozzle does not affect the quality of the fabric.

An economic analysis of the Machnozzle as a fabric predrying device was made for a number of cases. The results showed the Machnozzle to be an attractive investment. All the cases studied yielded positive Net Present Values. Simple paybacks as short as 3 1/2 months were calculated for the Machnozzle and associated equipment using a present fuel cost of $3.50 per 10^6 Btu.

1. INTRODUCTION

Phase I of the Georgia Tech project entitled "Energy Conservation in the Textile Industry" (Department of Energy Contract No. EY-76-S-05-5099) revealed that predrying and drying of textiles consumes approximately 8.8 x 10^6 barrels of oil equivalent energy annually or approximately 24% of the total energy consumed in wet processing of textiles (Reference 1). Predrying and drying processes have relied heavily on thermal energy to remove water and have been energy inefficient. Therefore, predrying and drying were targeted as processes where research and development in Phase II of the DOE project could lead to significant energy conservation.

During Phase II of the DOE project, methods for combining mechanical and thermal means of moisture removal were investigated (Reference 2). One of the moisture removal techniques involved the use of a novel drying device called a Machnozzle. The Machnozzle is designed to accelerate high pressure steam to sonic speed by passing it through a narrow slot. The fabric is passed across the slot exit where the high velocity steam flow creates a large pressure differential across the fabric. The water is then literally blown out of the fabric. The steam passing through the fabric loses little of its thermal energy and can therefore be mixed with cold water to yield a hot water source for the plant.

The major role of the Georgia Tech research on the Machnozzle was to evaluate and optimize the device while comparing the drying efficiency to the manufacturer's claims. A 16-inch long Machnozzle was purchased, and a test system was built which simulated projected plant conditions of fabric speed and steam pressures. Due to project limitations, no runs were possible on the unit before Phase II termination.

Additional funding was granted to Georgia Tech to continue the drying research (Reference 3). A major part of the research effort was directed at evaluating the Machnozzle as predrying device to be used just prior to final drying. The results of the study indicated that the Machnozzle was capable of significantly reducing fabric moisture content and that the energy requirements of the Machnozzle were much lower than those of conventional methods (infrared and steam cans) of predrying.

Since the pilot scale study suggested that a substantial reduction in energy required for drying fabrics could be achieved by utilizing a Machnozzle as a predrying device, a project has been conducted to demonstrate the Machnozzle as a predrying device on a commercial scale. The project was sponsored jointly by the Department of Energy and the J.P. Stevens and Co., Inc.

This report documents the in-plant demonstration and includes:

- A review of the pilot-scale research
- A description of the in-plant demonstration and methodology used
- Results of the Machnozzle tests, energy recovery tests, and quality assessment tests
- An economic analysis of the Machnozzle as a predrying device with and without energy recovery.

2. PILOT-SCALE STUDY OF A MACHNOZZLE AS A PREDRYING DEVICE

2.1 Background

A pilot-scale study was conducted at Georgia Tech to investigate the potential of the Machnozzle as a device for predrying fabrics. The study was part of a one year project entitled "Development and Demonstration of Energy-Conserving Drying Modifications to Textile Processes." The one-year project was sponsored by the United States Department of Energy [Part 2, Phase III extension of Department of Energy Contract No. EY-76-S-05-5099] and was conducted jointly by the Engineering Experiment Station and the School of Textile Engineering at Georgia Tech. The results of this project are reported in Reference 3.

Brugman Machinefabrik of the Netherlands developed the Machnozzle as a moisture removal device to be used in conjunction with washers manufactured by Brugman Machinefabrik. Claims made by Brugman indicated that the Machnozzle could significantly decrease the moisture content in fabrics and had a potential for reducing energy consumed in drying textiles. The claims suggested that the Machnozzle was capable of drying fabrics to lower moisture levels than may be obtained with other mechanical extraction systems such as pressure rolls, while having a much lower energy consumption than is required in thermal drying. However, problems were encountered with the application of the Machnozzle in the washer systems due to lint buildup on the Machnozzle.

Because of the high potential savings in drying textiles, Georgia Tech researchers considered applications of the Machnozzle where lint buildup would not be a problem. The application selected for study was the use of the Machnozzle as a separate unit functioning as a predrying device just prior to final drying. A pilot-scale study was conducted at Georgia Tech to evaluate the Machnozzle as a predrying device.

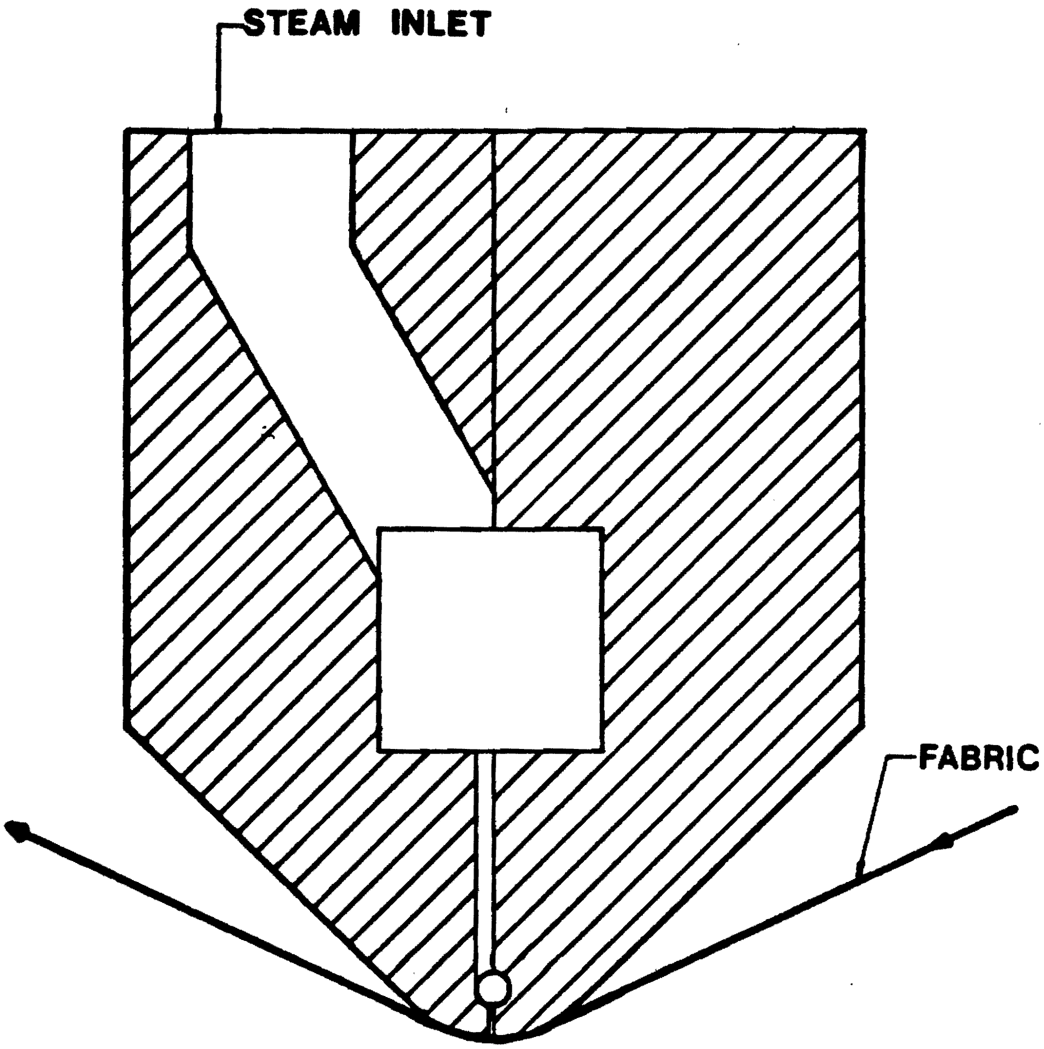
2.2 Description of Machnozzle

A cross section of the Machnozzle is shown in Figure 1. Steam or some other gas is fed by a pipeline to the Machnozzle. The steam flows at very low speed through most of the Machnozzle until it reaches a buffer chamber (the circular chamber located near the tip of the Machnozzle). As the steam leaves the chamber, it accelerates rapidly as it moves through a converging nozzle and then through a very narrow slit. At the exit of the nozzle, the steam velocity is sonic if the input steam pressure is sufficiently high.

A detailed analysis of the fluid flow in the Machnozzle was performed under DOE Contract Number DE-AS05-78CS-40098. The results of this analysis are included in Reference 4. The analysis predicted that a steam supply pressure of 100 psig would yield: 1) a Mach number at the slit exit of 1.0 (corresponding flow velocity was 1582 ft/sec), 2) a static pressure at the slit exit of 47 psig, and 3) a mean coefficient of friction in the slit of 0.00246.

When fabric is passed across the exit of the slit, the high velocity steam flow creates a large pressure differential across the fabric. Water and residual matter entrained around and in the yarn are literally blown out of the fabric, with little heat transfer occurring. The steam passing through the fabric loses little of its thermal energy and can be passed through a condenser where it is mixed with cold water to yield a hot water source for the plant. Thus much of the energy in the steam can be recovered, making the predrying process much more energy efficient.

While the Machnozzle may be operated with either steam or compressed air, the pilot-scale study was conducted using steam. Many textile mills may require additional compressor capacity in order to supply air at a sufficient pressure and flow rate to operate the Machnozzle, whereas the total mill steam consumption would be reduced when steam is used to operate the Machnozzle.



MACHNOZZLE

Figure 1 Cross Section of the Machnozzle

2.3 Testing

A test system was designed and constructed for evaluating the performance of the Machnozzle as a predrying device. The effect of the following parameters on the effectiveness of the Machnozzle in removing moisture were studied:

- Fabric type
- Fabric speed
- Steam supply pressure
- Process parameters
    1. wrap angle
    2. fabric tension
    3. incoming fabric temperature
    4. Machnozzle slot width

Three types of fabrics, 100% cotton, 50/50 cotton/polyester, and 100% polyester, were tested. Fabric speed was varied from 20 to 80 meters per minute and steam supply pressures of 50, 75, and 95 psig were tested. The effects of several process parameters were investigated.

2.4 Results

The effectiveness of the Machnozzle in removing moisture from the three types of fabrics was measured. The response monitored during these tests was regain which is defined in Reference 5 as follows:

$$\text{Regain} = \frac{\text{Weight of Water in Fabric}}{\text{Bone Dry Fabric Weight}} \times 100\%.$$

Results of tests for fabric speeds ranging from 20 to 80 m/min and steam supply pressures of 95, 75, and 50 psig are shown in Figures 2, 3, and 4.

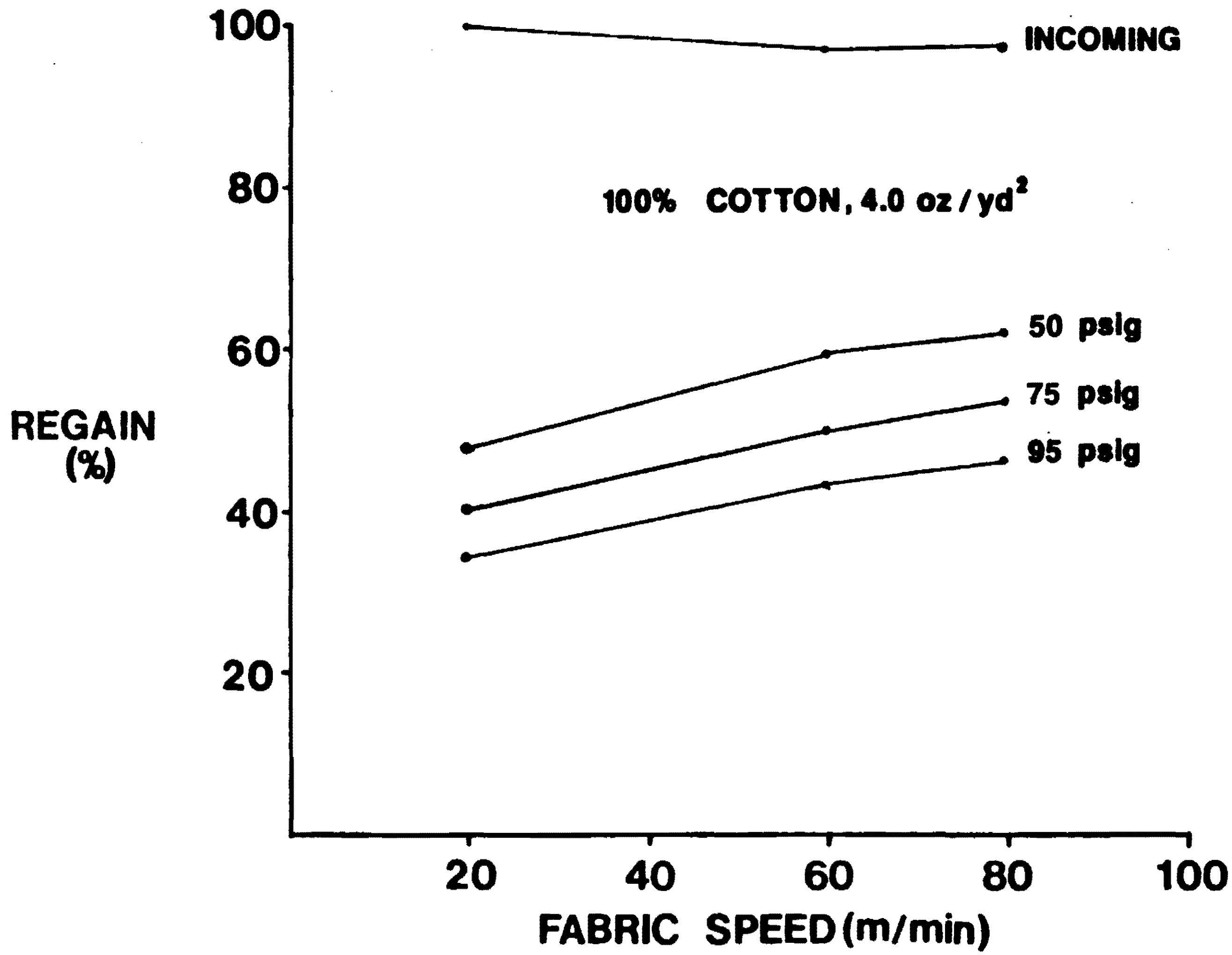


Figure 2 Regain versus Fabric Speed for 100% Cotton Fabric

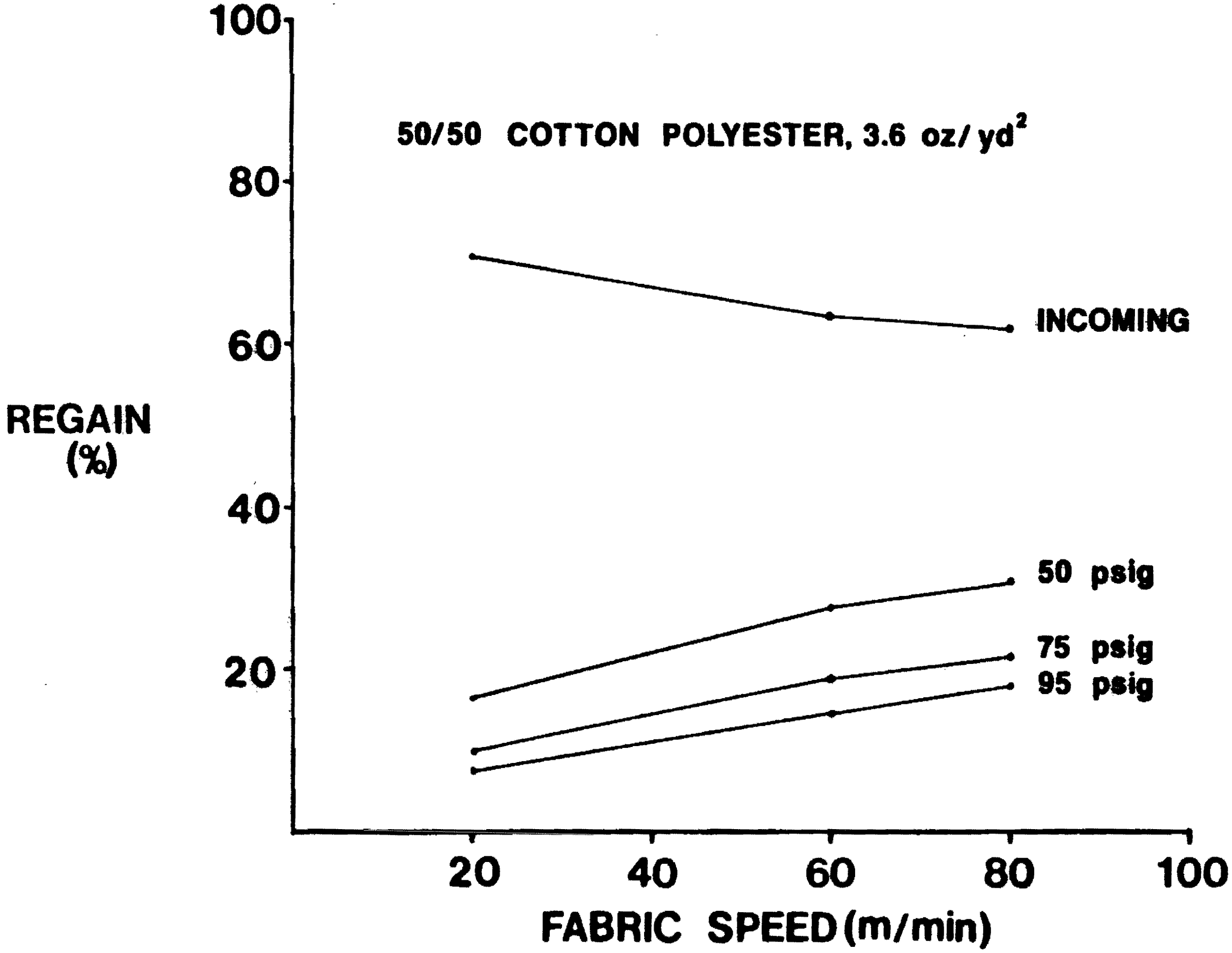


Figure 3 Regain versus Fabric for 50/50 Cotton/Polyester Fabric

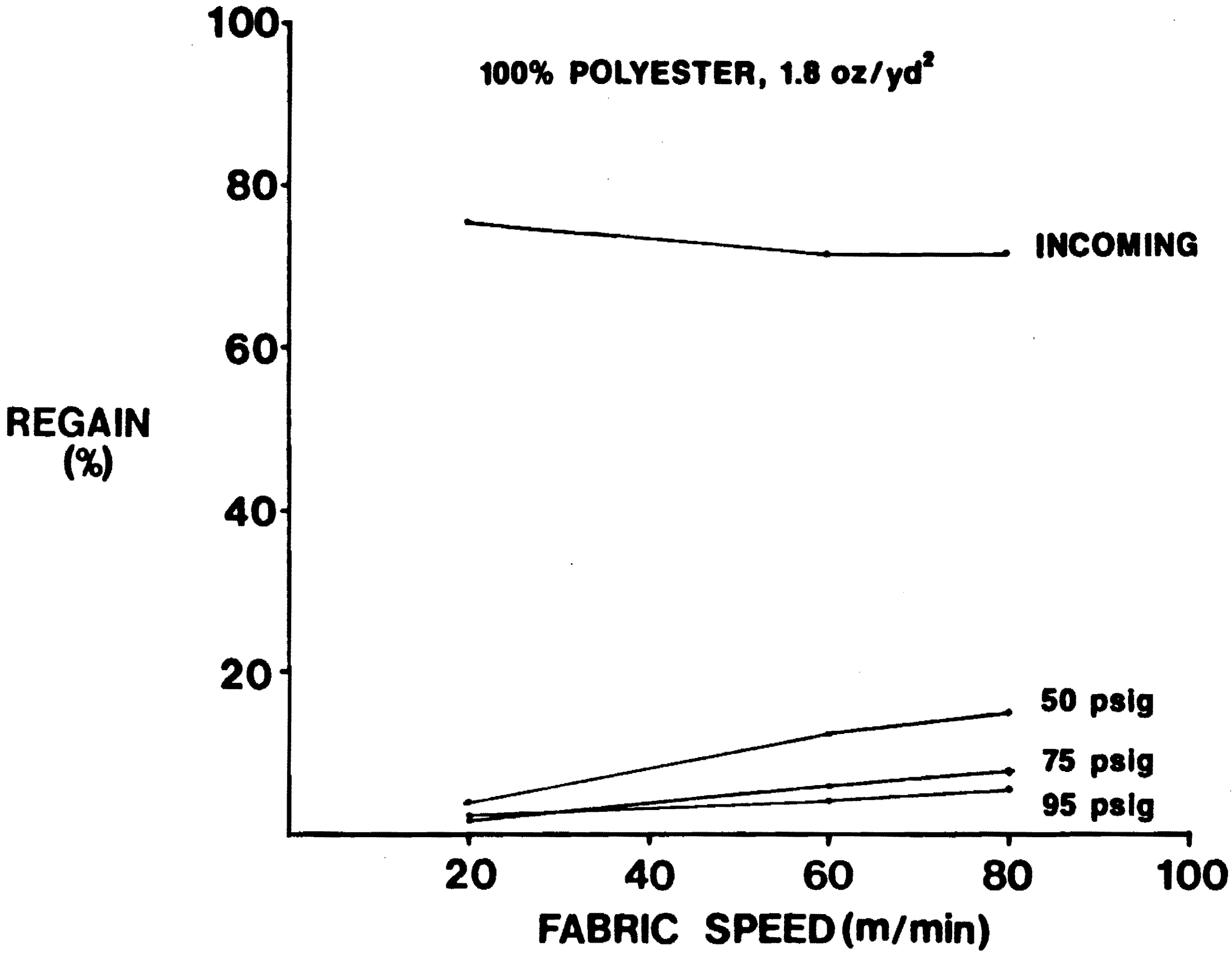


Figure 4 Regain versus Fabric Speed for 100% Polyester Fabric

After passing through the squeeze rolls, 100% cotton fabrics weighing 4.0 oz/yd^2 had a regain of approximately 97%. The Machnozzle reduced the regain to 34 and 46% for fabric speeds of 20 and 80 m/min, respectively, at a steam supply pressure of 95 psig.

After passing through squeeze rolls, the regain of 50/50 cotton/polyester fabric weighing 3.6 oz/yd^2 was approximately 68%. The regain was reduced by the Machnozzle to 7 and 17% for fabric speeds of 20 and 80 m/min, respectively, at a steam supply pressure of 95 psig. The Machnozzle was extremely effective in removing moisture from 100% polyester fabric weighing 1.8 oz/yd^2. The regain was reduced from approximately 61% to 3 and 6% for fabric speeds of 20 and 80 m/min, respectively, at a steam supply pressure of 95 psig. The results showed that as the fiber in the fabric was changed from cotton to polyester, lower regains were obtained using the Machnozzle. These results were expected since cotton is hydrophilic while polyester is hydrophobic.

The effect of increasing the steam supply pressure on fabric regain after passing over the Machnozzle is illustrated in Figures 2, 3, and 4. Plots of regains versus fabric speed are given for steam supply pressures of 50, 75, and 95 psig for the three fabrics. As steam supply pressure was increased, regain was reduced. For example, for polyester fabric at a fabric speed of 80 m/min regain was reduced from 15 to 6% as steam supply pressure was increased from 50 to 95 psig.

The steam consumed in removing a pound of water varied with fabric speed and steam supply pressure as shown in Figure 5. The steam consumption decreased as fabric speed was increased even though lower regains were obtained at lower fabric speeds. This occurred because the rate at which steam was consumed by the Machnozzle was nearly constant and independent of fabric speed. As fabric speed was increased, the quantity of fabric processed per unit time by the Machnozzle increased. As a result, steam consumption per pound of water removed decreased as fabric speed increased. As steam supply pressure was increased, steam consumption per pound of water removed increased at low fabric speeds. However, at a fabric speed

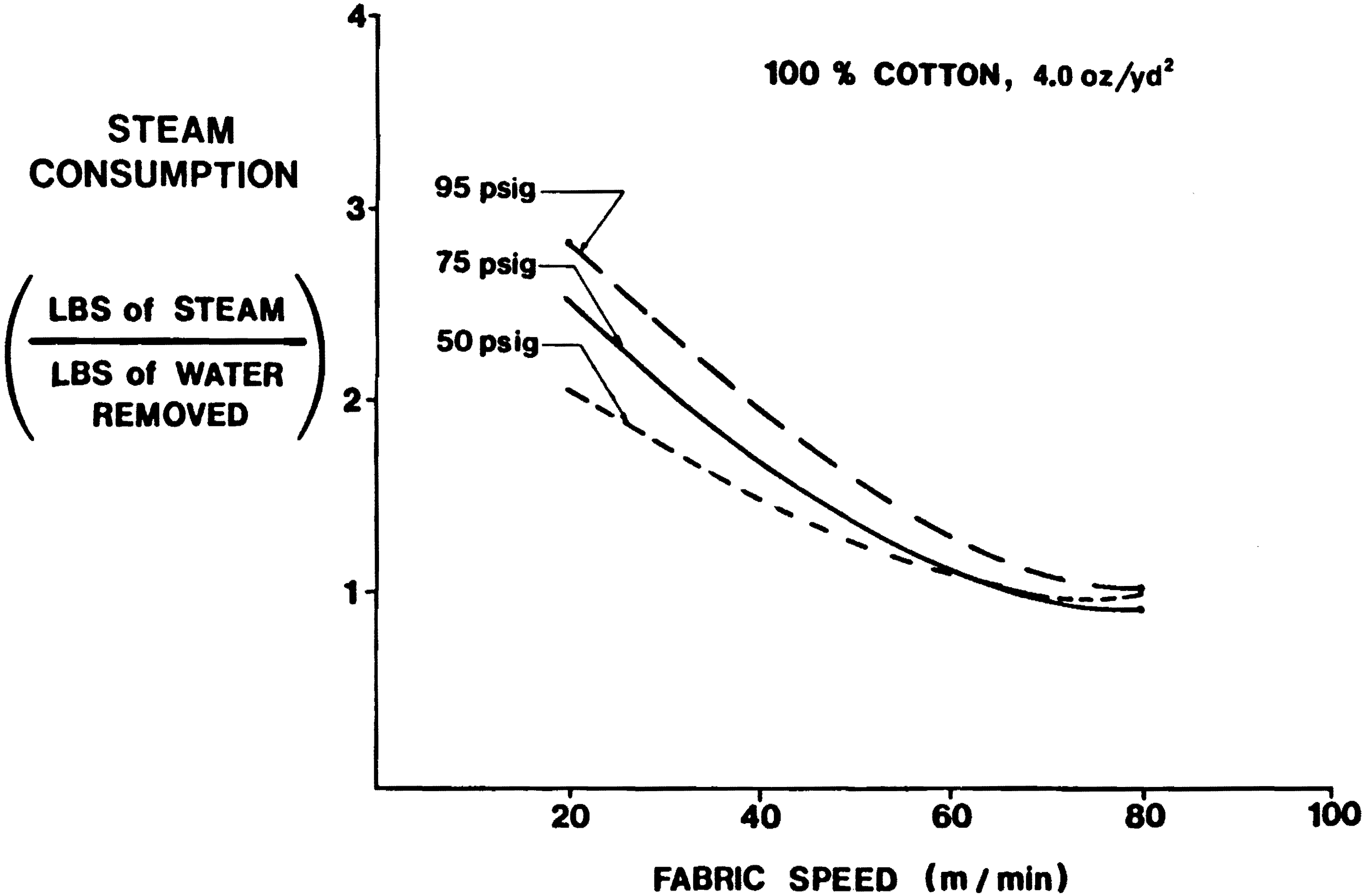


Figure 5 Steam Consumption of Machnozzle without Energy Recovery

of 80 m/min, there was little difference in steam consumption per pound of water removed. Since more moisture was removed at the steam pressure of 95 psig, the Machnozzle would probably be operated at 95 psig or higher under commercial conditions.

The steam consumption for a fabric speed of 80 m/min and a steam supply pressure of 95 psig was approximately 1 pound of steam per pound of water removed. The steam requirements of steam can dryers are normally assumed to be between 1.5 and 2.5 pounds of steam per pound of water removed. Thus the low steam requirements of the Machnozzle suggested that this device has a potential for saving energy in the fabric drying process.

Another factor that makes the Machnozzle an attractive low-energy consuming predrying device is that much of the energy in the steam used by the Machnozzle can be recovered. By passing the steam through a condenser where it is mixed with cold water, a hot water source is produced for the plant. Tests run on a condenser built at Georgia Tech indicated that approximately 70% of the energy in the steam used by the Machnozzle can be recovered. If a condenser capable of recovering 70% of the energy in the steam is used, the steam consumption of the Machnozzle is shown in Figure 6. At a fabric speed of 80 m/min, the steam consumption of the Machnozzle is approximately 0.3 pounds of steam per pound of water removed.

The curves shown in Figures 5 and 6 are for 100% cotton fabric; however, similar results were obtained for 50/50 cotton/polyester and 100% polyester fabrics. Thus the results illustrated in Figures 5 and 6 can be considered representative of the performance of the Machnozzle for fabrics weighing approximately 4 oz/yd^2.

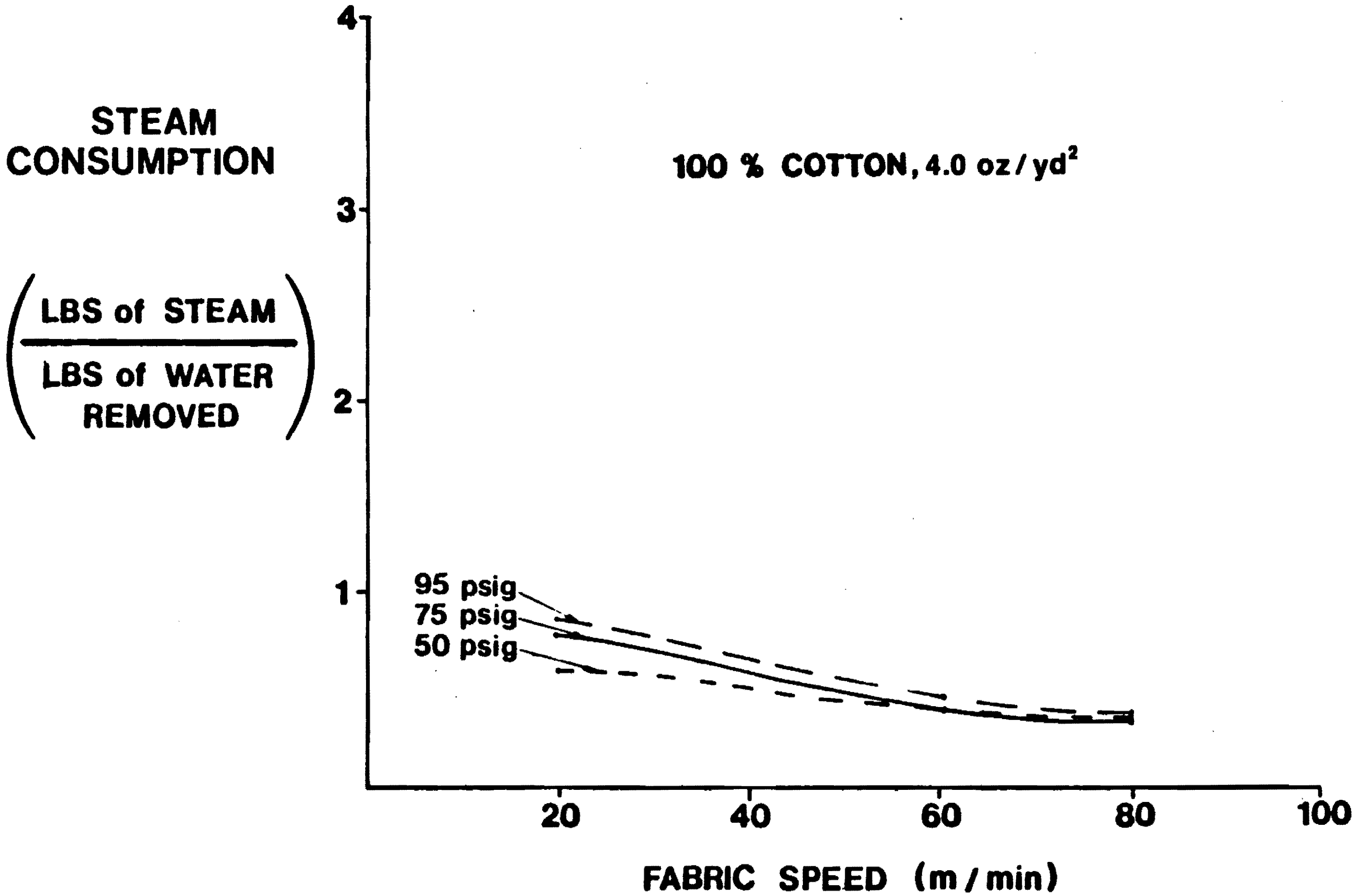


Figure 6 Steam Consumption of Machnozzle with Energy Recovery

3. IN-PLANT DEMONSTRATION

3.1 Objective

The objective of this research project was to demonstrate on a commercial scale the Machnozzle as a predrying device for fabrics. To accomplish the objective, the following tasks were to be performed:

1) to establish baseline energy requirements for final drying of fabrics on a commercial scale.

2) to measure the total energy consumption of the final drying process with the Machnozzle used as a predrying device.

3) to determine the percentage of the steam energy, used by the Machnozzle, that can be recovered as hot water.

4) to determine the effect of the Machnozzle on product quality.

5) to evaluate the potential energy and economic impact of the Machnozzle on the final drying of fabrics on a commercial scale.

All of these tasks were accomplished during the course of this research project. Tasks 1 and 2 are discussed in Section 3.6. Task 3 is discussed in Section 3.7. Task 4 is discussed in Section 3.8. Task 5 is discussed in Section 4.

3.2 Demonstration Site

The in-plant demonstration program was conducted at the J.P. Stevens and Co., Inc. Delta #1 Plant near Clemson, South Carolina. The 1100-mm

(43.3-inch) Machnozzle and related equipment and instrumentation were installed on Range Number 6, a 120-inch-wide preparation and finishing line for sheeting fabrics. The range consisted of a scray; a wash box and mangle; three, ten-can stacks of steam dryer cans; a pad for finish application; an infrared predryer; another ten-can stack of steam dryer cans; a 90-foot-long tenter frame; and a winder. The Machnozzle was installed between the first pad and the first steam dryer can stack (See Figure 7). The Mahlo fixed, moisture monitoring equipment was also located in this area. The condenser and related equipment was located beside the range (See Figure 8).

3.3 Equipment

It was necessary to design and fabricate several pieces of equipment for the project. Other equipment was purchased or already on hand. Two major project requirements were mounting an existing 1100-mm Machnozzle, purchased under Department of Energy Contract Number DE-AS05-78CS-40098, on Finishing Range Number 6 and designing and fabricating a condenser to recover the energy from the steam exhausted by the Machnozzle. The resulting equipment is described below. A complete set of drawings is included as Appendix A.

Machnozzle Fixture - The objective of the demonstration program was to test the effectiveness of the Machnozzle as a predrying device for fabrics. This necessitated that the Machnozzle be located between the mangle and the steam dryer cans. Therefore, it was necessary to fabricate a structure to install the Machnozzle in this location.

There were a number of restrictions placed on the design. Finishing Range Number 6, a 120-inch-wide range, had been selected by the plant management for the demonstration. The space between the mangle and the first steam dryer can stack was very limited; they were separated by about two feet. Since the Machnozzle was only 43.3 inches wide, provisions had to be made to move the nozzle away from the fabric when the machine was

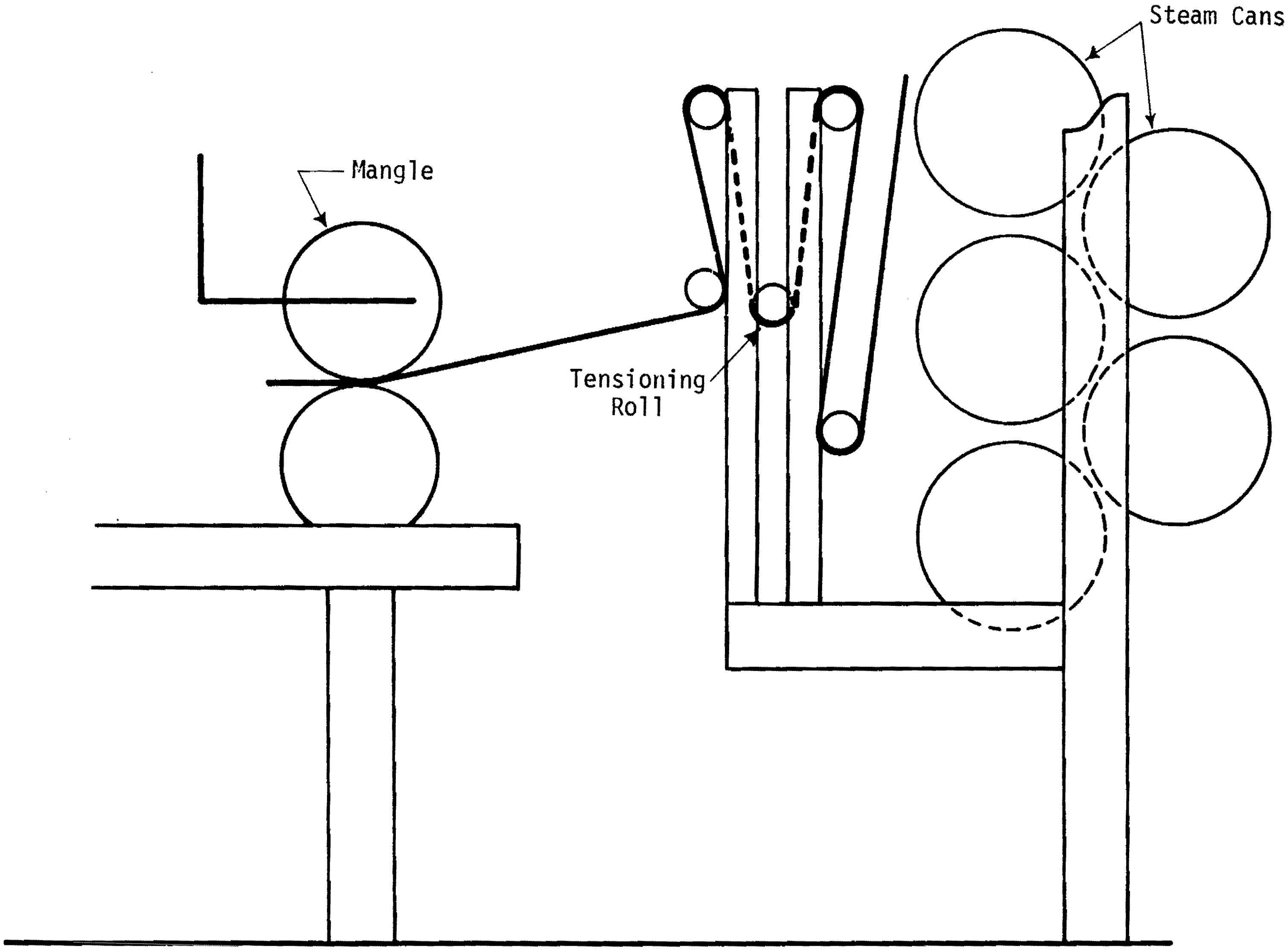


Figure 7 Mangle and First Can Stack

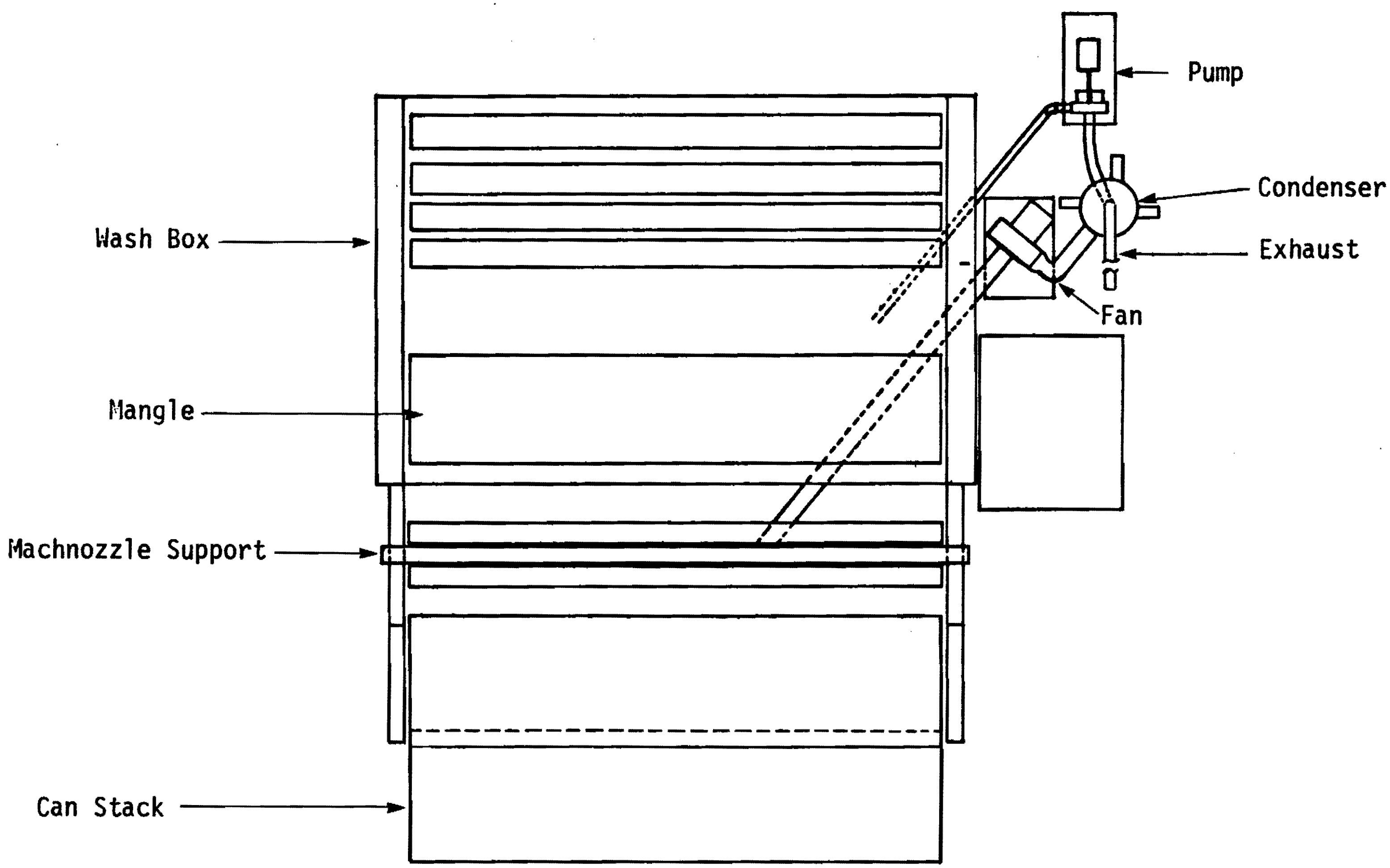


Figure 8 Plan View of Equipment Layout

running fabric wider than 43 inches. It was believed that the Machnozzle should be extended because the fabric widths might exceed the Machnozzle width by one or two inches and because the fabric position does vary from side to side while the machine is running. Guide rollers were necessary to give the proper fabric wrap angle around the face of the Machnozzle. Also, two vertical runs of fabric with space on both sides of the fabric were needed for the two-sided moisture monitoring device. The Machnozzle had to be accessible for teardown in case the exit slit became clogged. Finally, the structure needed to be sufficiently strong to withstand loads that might be placed on it in the event that the fabric jammed and to meet with the approval of the plant engineer and shop manager.

The final design for the Machnozzle mounting fixture is shown in Figures 9 & 10. The structure consists of two h-shaped frames welded out of 4 inch x 4 inch x 3/16 inch wall steel tubing. One-half-inch steel plates were drilled, tapped, and welded to the face of the tubing on which to mount pillow blocks. Five guide rolls were mounted between these two frames. They provided two vertical fabric paths for location of the moisture monitor and forced the fabric to touch both faces of the Machnozzle. The Machnozzle was attached to a C-channel beam which was supported between the two frames. Two, four-inch-long "dummy" Machnozzles were fabricated from Type-304 stainless steel and attached to the beam at each end of the Machnozzle. The beam was supported at each end by a double-acting pneumatic cylinder with six inches of travel. The pneumatic cylinders were used to raise the Machnozzle out of contact with the fabric when it was not in use and to hold the Machnozzle down in place when it was in use. This also made it possible to split the Machnozzle halves in order to clean the exit slit. The shop drawings are included in Appendix A.

The frames were fabricated at Georgia Tech then delivered to Clemson. Plant maintenance personnel performed most of the equipment installation. The frames were aligned and installed in position. Then the rollers, which were supplied by J.P. Stevens and Co., Inc., were installed. A local Atlanta machine shop fabricated the "dummy" Machnozzles and beam and

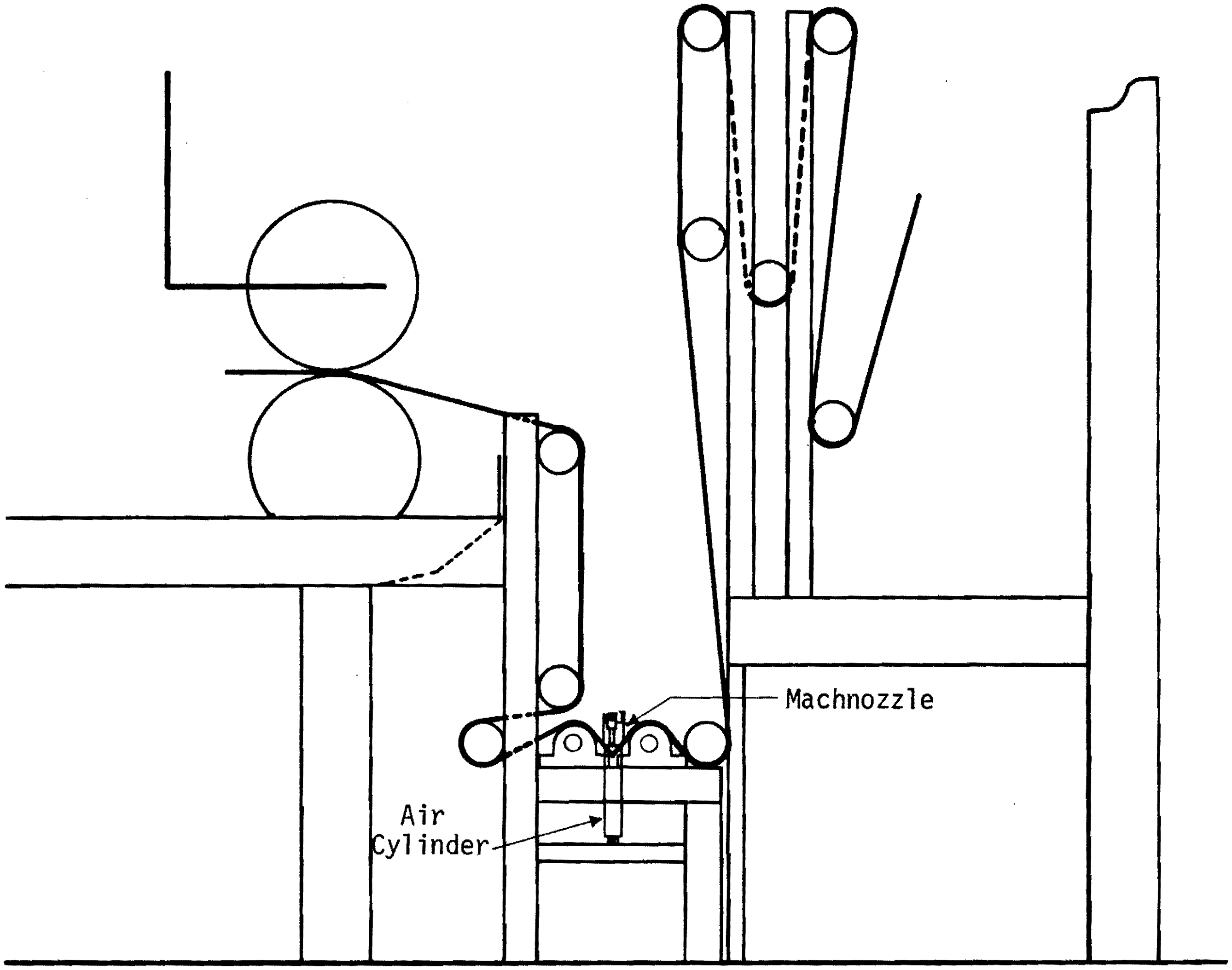


Figure 9 Schematic of Machnozzle Installation

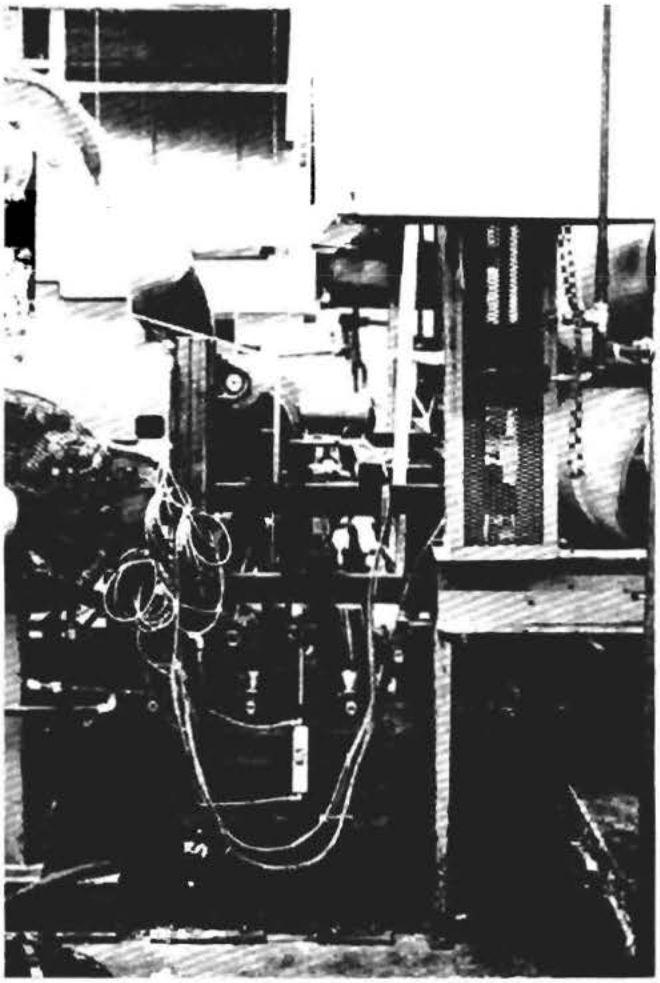


Figure 10 Installed Machnozzle and Mounting Fixture

assembled the beam, Machnozzle, and "dummy" Machnozzles. The beam assembly was installed on the frame and the pneumatic cylinders were attached and piped up. The steam piping was then begun. Several changes were made in the steam piping in an attempt to solve the problems of wet steam, trash in the steam, and low steam pressure. The final steam piping configuration is shown in Figure 11. The piping incorporated a drop leg and steam trap and a strainer to clean up the steam initially. A pressure regulating station and by-pass line were provided to allow the Machnozzle to be operated at line pressure or at some pressure below line pressure. An Anderson Type LC200 downflow centrifugal separator was used to remove particles from the steam to prevent clogging of the Machnozzle slit. An orifice plate was installed in the line to allow monitoring of the Machnozzle steam flow. A blowdown valve was provided. The steam piping was connected to the Machnozzle by flexible brass lines so the Machnozzle could be raised or lowered. The Machnozzle was supplied from the very end of an extremely long main steam header. The steam supply pressure was lower than desired during the first days of testing. This problem was solved by raising the boiler pressure 25 psig for the duration of the test.

Condenser - One of the project objectives was to determine how much of the steam energy exhausted by the Machnozzle could be recovered as hot water. This necessitated the purchase or design and construction of a condenser system. A counter-flow, direct-contact condenser was selected since the hot waste stream was assumed to contain only air, water, and steam. A brief literature search yielded References 6, 7, and 8 on direct-contact heat exchangers.

Reference 7, by Harlan How, contained some design suggestions and guidelines for direct-contact condensers. Many of these suggestions were incorporated into the initial design shown in Figure 12. The design guidelines were used to size the condenser body, inlet, outlet, and water inlet. Reference 7 suggested using a weir tray to introduce streams of cold water at the top of the column. How recommended using the weir tray instead of nozzles or a tray that yielded a continuous sheet of water. This recommen-

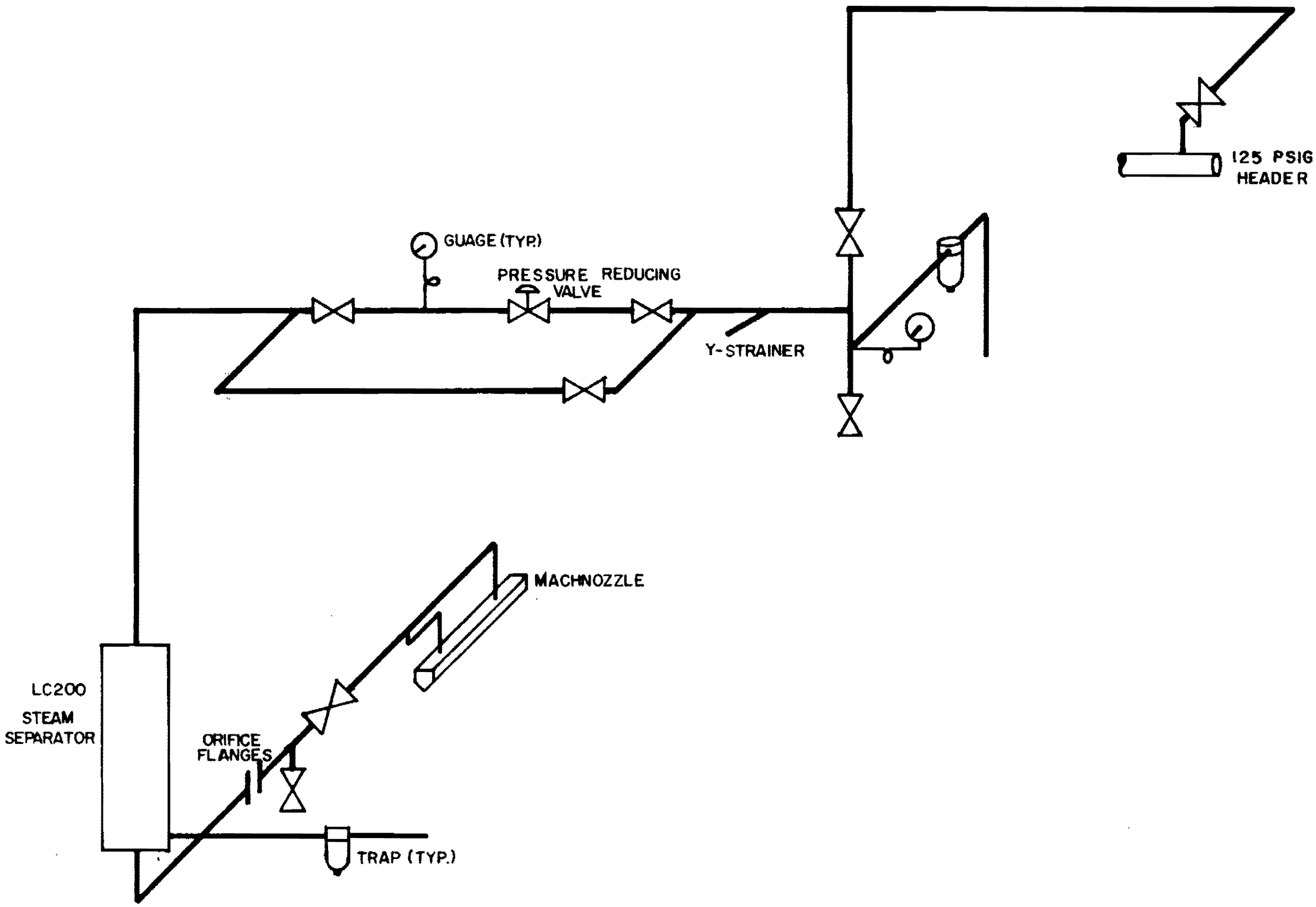


Figure 11 Final Steam Piping Configuration

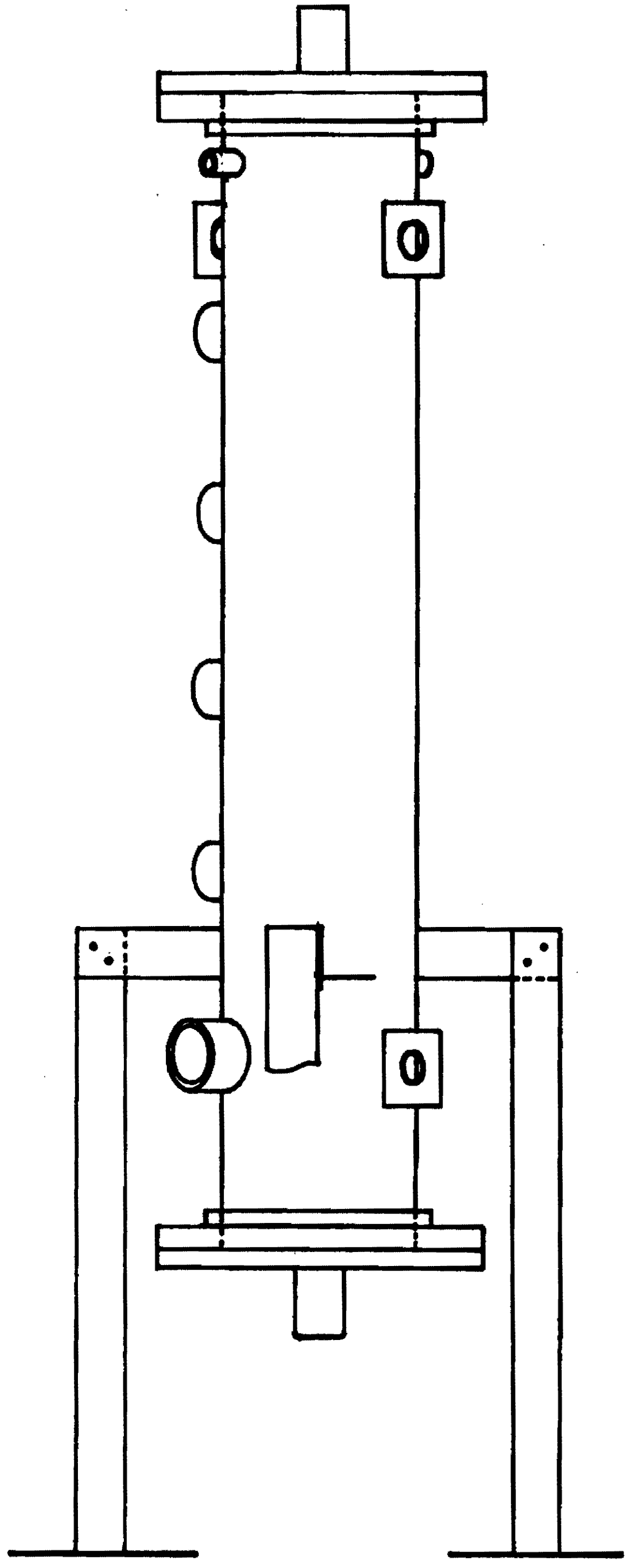


Figure 12 Schematic of Condenser Column

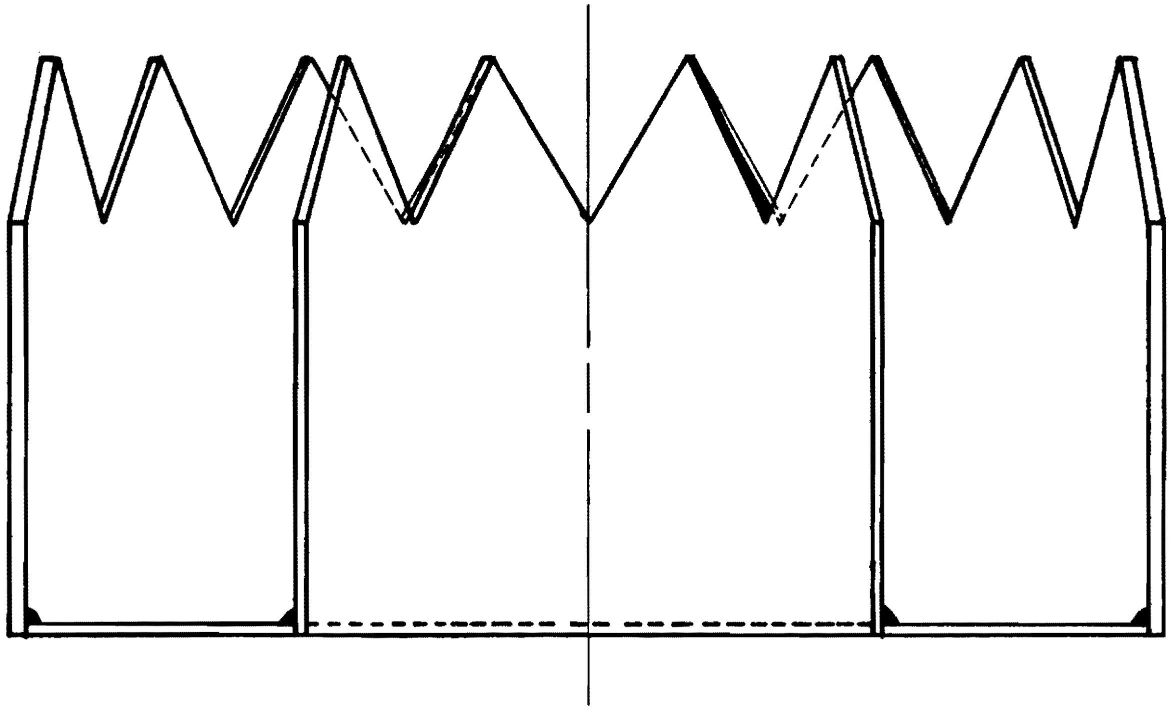
dation was followed initially.

The condenser column design was based on standard pipe and fittings to reduce the labor cost on this one-of-a-kind piece of equipment. The column body was made from a four-foot piece of 8-inch, schedule 40 pipe with 150-pound, slip-on flanges at each end. Thread-a-lets were welded on the side to provide inlets for the steam and cold water and ports for visual observation and temperature measurements. Half-couplings were welded on to blind flanges for the top and bottom. The bottom was used as the hot water outlet, and the top as the exhaust air outlet.

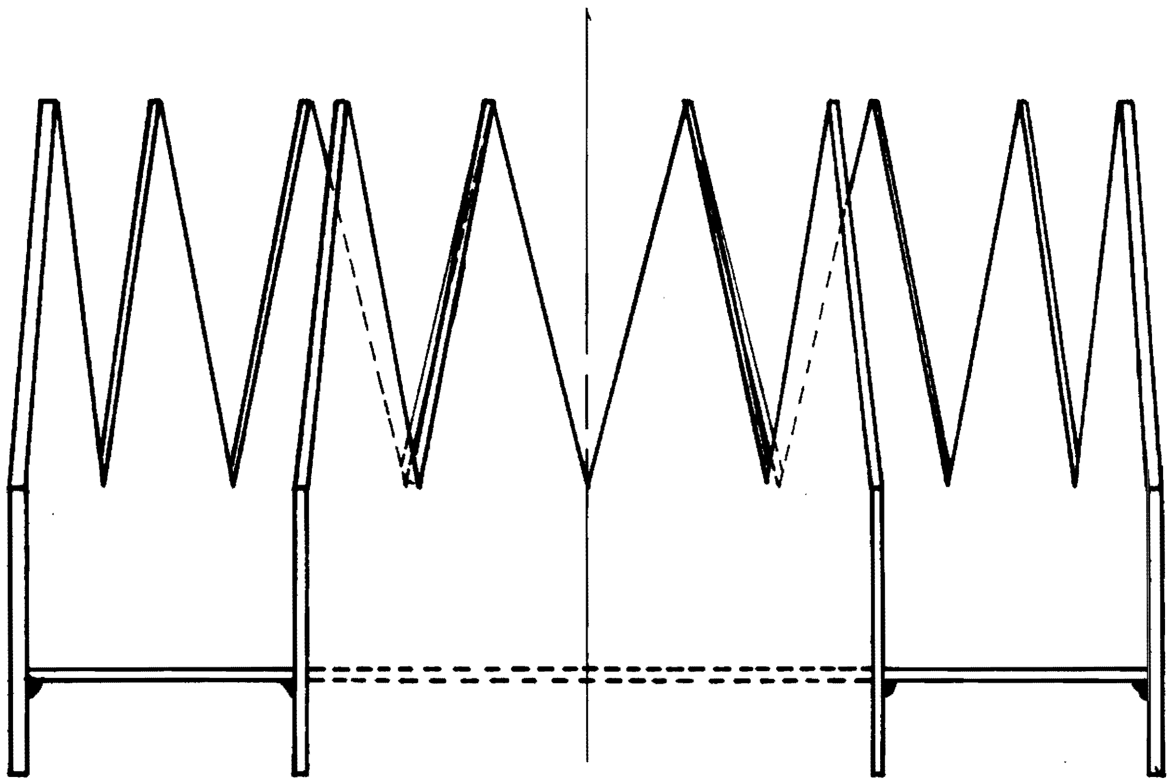
Initially, a weir tray was used to introduce streams of cold water at the top of the column. The first weir tray used is shown in Figure 13. The tray did not give satisfactory performance. At the required flow rates, the outer streams of water tended to follow the tray surface around the bottom and join the streams in the center. The result was that most of the cold water fell down the center of the column while most of the hot air and steam flowed up the outside of the column. The exhaust temperatures were very hot while the hot water temperatures were quite low. A second weir tray, also shown in Figure 13, was built to solve this problem. The condenser performance with the new weir tray was not significantly better. A decision was made to try a nozzle in place of the weir tray.

Four different nozzles were tested. Initial flow rate versus pressure measurements were made. Two of the nozzles proved to have unsatisfactory spray patterns at the desired flow rates. The other two nozzles were tested with the condenser operating, but without fabric running on the finishing range. A pump was used to boost the low, water line pressure to approximately 15 psig. Time limitations made it possible to test only one nozzle with the finishing range in operation. A Spraying Systems 30° Fulljet nozzle, model number 1¼HH30200 steel, was selected for the test. This nozzle gave a full cone pattern with a 30° cone at a 40 psig supply pressure. The condenser performance was greatly improved with the substitution of the nozzle for the weir tray.

The condenser system required several pieces of peripheral equipment in



Cross Section of First Weir Tray



Cross Section of Second Weir Tray

Figure 13

addition to the condenser column. This equipment included a steam collector trough located immediately below the Machnozzle, a fan to pull the steam and air into the column, and a pump to pull the hot water out of the condenser. Also, thermocouple wells were installed to measure the hot water outlet temperature and temperatures in the column. A Kent C-700 water meter was installed on the cold water line to meter the cold water input.

The steam collector trough, was fabricated from 18 gage, galvanized steel. The trough was modified several times during the course of the experimentation to the final configuration shown in Figure 14. The wipers and end seals were used to reduce the amount of air that was pulled into the trough. The wipers were fabricated from Melinex® polyester film manufactured by ICI, Inc. They actually rubbed against the moving fabric. The end blocks were cut from 3/4 inch basswood. The seals were very effective, however, the life of the polyester film seal is unknown. Steam and air were pulled from the side outlet to the condenser. The water, lint, and impurities that were blown out of the fabric went through the bottom outlet to the drain. This water was quite hot, 205°F, but contained a significant amount of lint. The lint caused clogging problems in the drain line.

A small, fractional-horsepower blower was installed on top of the condenser to pull steam and air from the trough to the condenser and to exhaust the air from the condenser to the steam dryer can hood. During the early testing, it appeared that this fan would be inadequate for the job. A second, larger fan was installed between the steam collector trough and the column. Later, improvements to the wipers and end seals resulted in a great reduction in the amount of air that entered the steam collector trough. This in turn, reduced the air pumping requirements and need for a second fan.

A one horsepower centrifugal pump, manufactured by Dean Brothers Pumps, Inc. was used to pump the hot water out of the condenser to drain. The pump, Model Number PH-201, was available at Georgia Tech, was adequate for the needed flow rate, and would withstand the hot water temperatures.

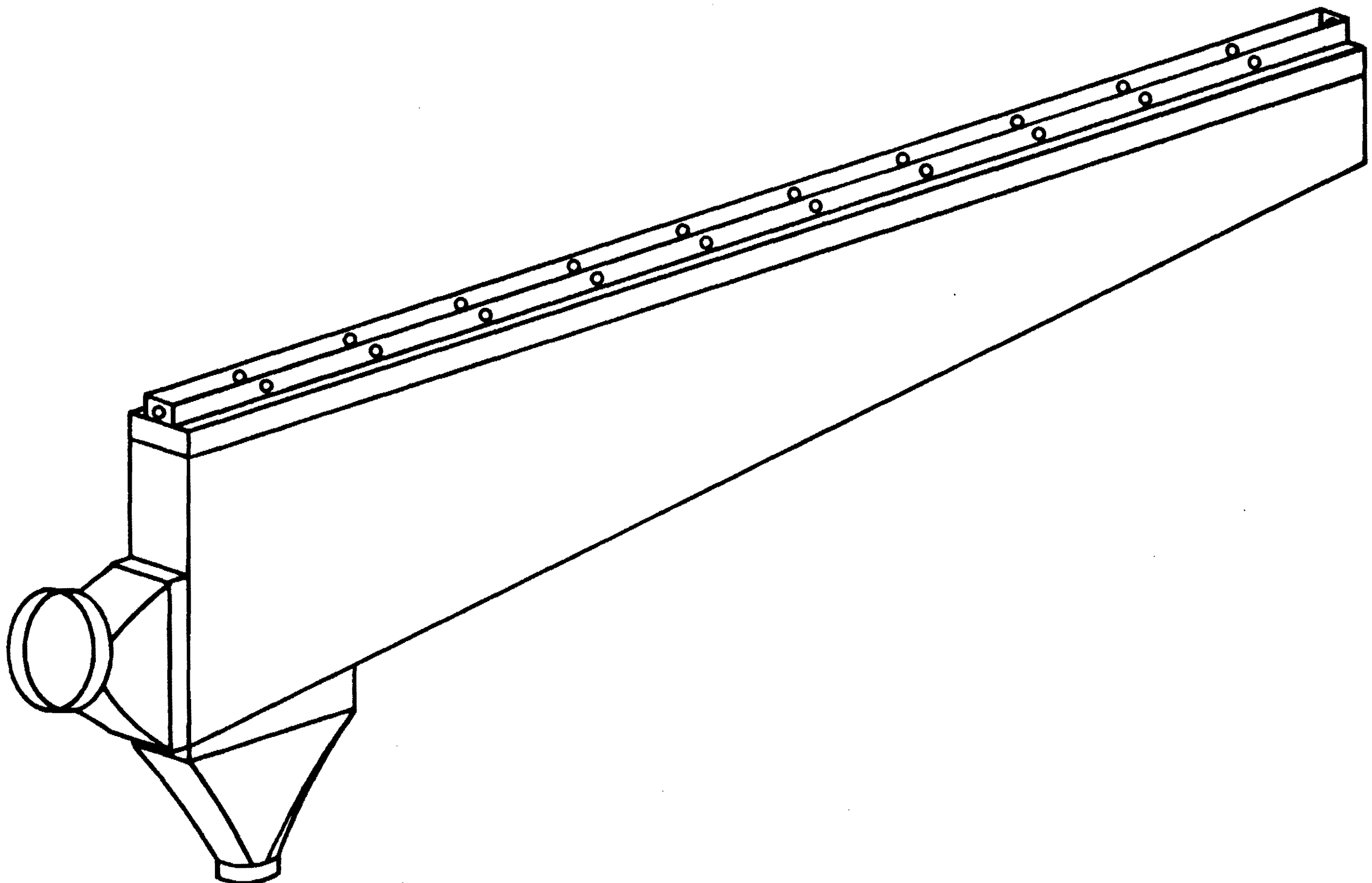


Figure 14 Schematic of Steam Collector Trough

The entire condenser system is shown in Figure 15. A great deal of development work was required during the testing program to make the condenser system perform adequately. This meant that the testing time available for the final condenser system configuration was severely limited. However, enough information was generated to modify the condenser design for improved energy recovery.

3.4 Instrumentation

Several instruments were used to make the various measurements that were necessary for this project. The major pieces of instrumentation are discussed in this section. Appendix B contains the model numbers and serial numbers of the instruments that were used.

Moisture Monitoring Equipment - Moisture monitoring equipment was used during the in-plant demonstration so that the Machnozzle tests would not interfere with the operation of the continuous drying range. A survey of available moisture monitoring equipment was made to find a suitable device. The basic requirement of the moisture monitoring equipment was that it be capable of accurately measuring fabric regain before and after the Machnozzle. To meet this requirement, the moisture monitor had to measure fabric regain over the range of approximately 20 to 100%.

In addition to measuring regain before and after the Machnozzle, determining regain at various locations in the dryer section of the range was desired. Since regain in the dryer section could be as low as 0%, an instrument capable of measuring regain from 0 to 100% was needed.

The following four types of moisture monitoring devices were considered during the survey: infrared, microwave, dielectric, and electrical conductivity. No infrared device that was suited for the in-plant demonstration was found. A moisture monitoring device of each of the other three types were selected for tests.

Mahlo's Aqualot, Type HMF unit (a microwave apparatus) was chosen to measure regain before and after the Machnozzle. The unit had the capabil-

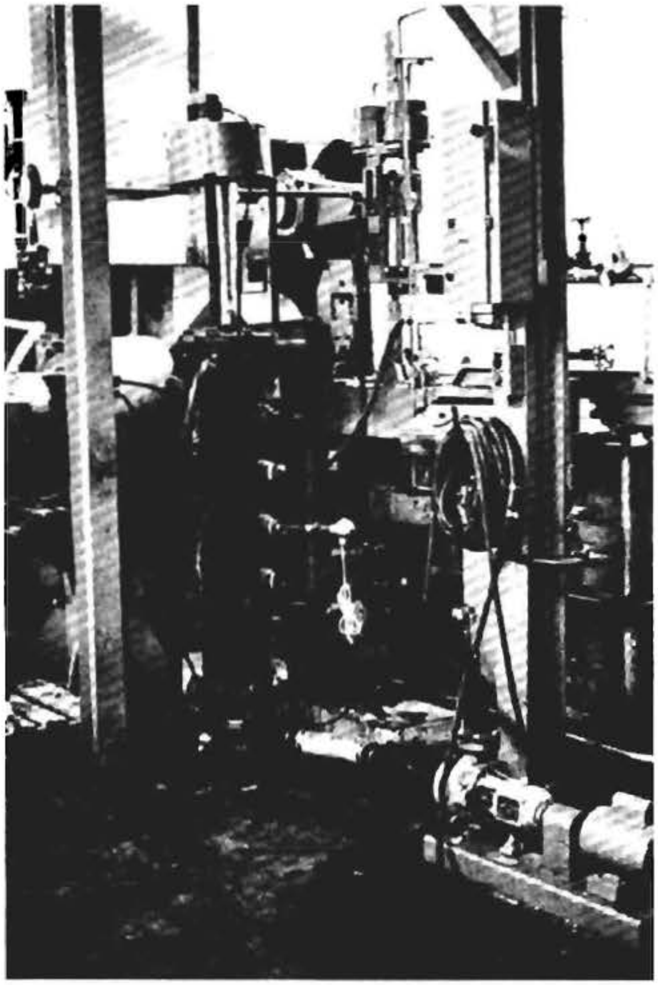


Figure 15 Condenser Column and Associated Equipment

ity of measuring moisture levels between 20 and 300 grams per m^2 with an accuracy of $\pm$ 0.5 grams per m^2. Since the weight of fabric to be processed during the in-plant demonstration was approximately 3.7 ounces per square yard, the range of moisture regain that could be monitored with Mahlo's Aqualot unit was from approximately 16 to 240%. The unit had the desirable characteristic of being a non-contact, two-sided apparatus, which was particularly advantageous when measuring high regains. The possibility of incurring sensor fouling due to the high quantity of water content on the fabric was avoided. The microwave transmitter and receiver heads are shown in Figure 16. The instrument's indicator is shown in Figure 17.

Mahlo's DB7-7 portable moisture monitoring device was selected to measure moisture regain below 16%. The range of moisture regain that the device (an electrical conductivity apparatus) was reported to be capable of measuring was from approximately 1 to 30%.

Atmospheric Sciences, Inc.'s portable moisture monitoring device (dielectric-type) was chosen to be used as a back-up device during the in-plant demonstration. The instrument had been used primarily in the wood and wood-product industries, but Atmospheric Science's representative stated the device should be suitable for monitoring moisture in textiles. For the weight fabric tested during the in-plant demonstration, the instrument could potentially measure regain over the entire range (0 to 100%).

The dielectric and electrical conductivity devices were found to be inferior to the microwave device. The major limitations of the two devices was their sensitivity to fabric weight, fabric type, and process speed. Both required extensive calibration at various process speeds for each fabric weight and fabric type.

The microwave device was found to be an excellent instrument. Accurate and repeatable results were obtained with the microwave device over a wide range of regain. The output of the instrument was independent of fabric type, fabric weight, and process speed. Thus, calibration of the instrument was much simplier than that of the other two devices.

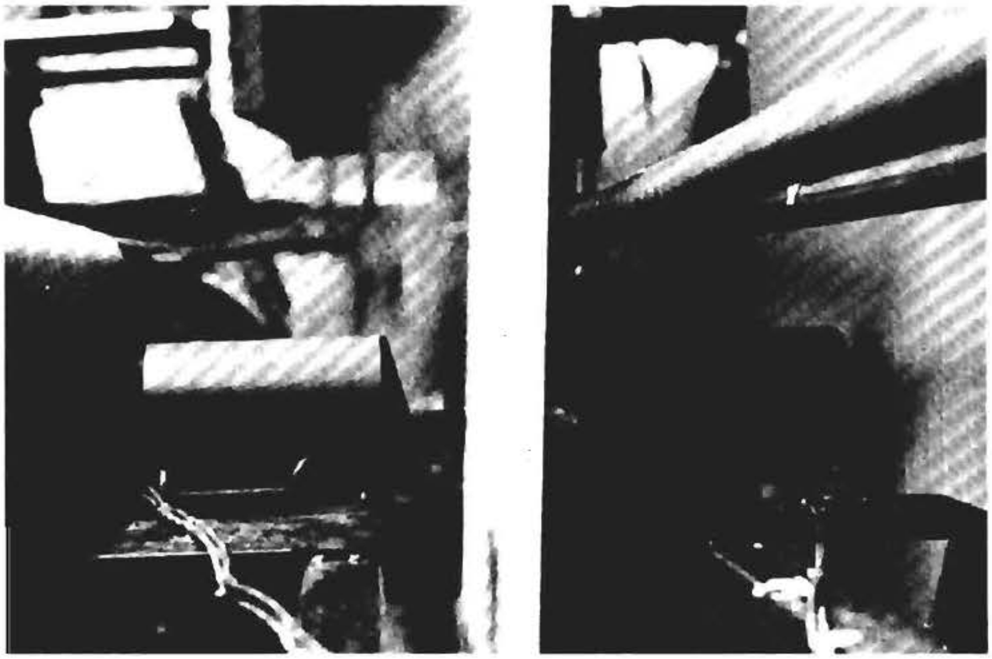


Figure 16 Mahlo's Aqualot Type HMF Microwave
Transmitter and Receiver

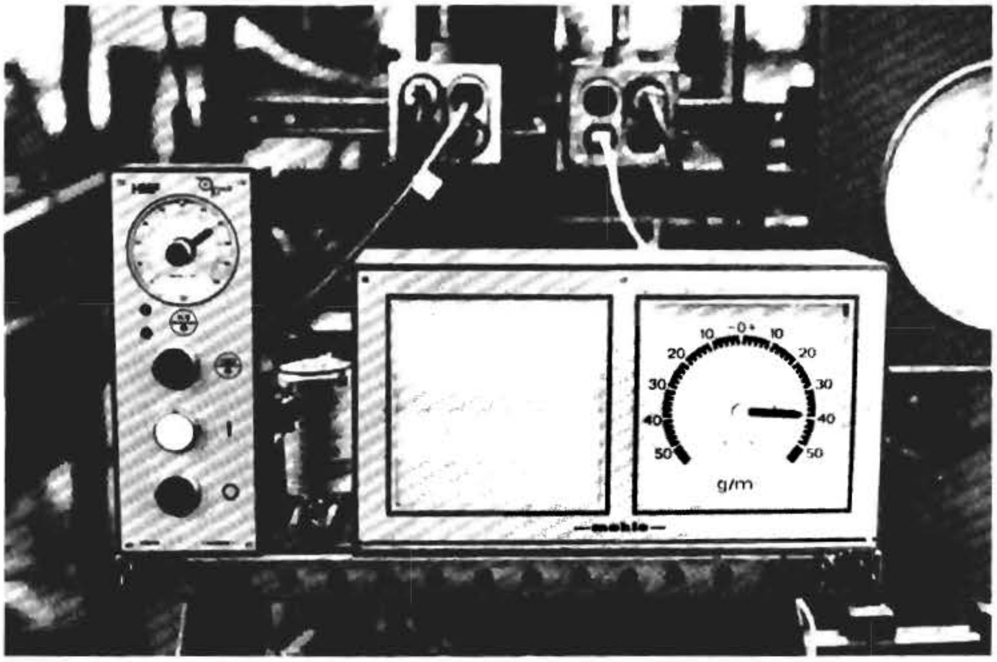


Figure 17 Mahlo's Aqualot Type HMF Indicator

Steam Flow Monitors - Determination of the efficiencies of drying with the Machnozzle and the steam cans required careful measurement of steam consumption. Steam flow measurements were made by determining pressure drops across orifice plates inserted into the steam lines. Two fixed steam flow monitors and a portable flow monitor were used with the orifice plates to measure both instantaneous flow rates and total flow.

Orifice plates were installed in the steam line connected to the Machnozzle, in the main steam header feeding the four stacks of steam cans, and in the lines feeding the individual stacks of cans. The main header installation is shown in Figure 18. The orifice plates (see Figure 19) in the lines connected to the individual stacks of steam cans permitted measurement of steam consumption at different stages of drying including the bone-dry condition. Closing the valves to the individual stacks allowed measurement of steam consumption of unneeded stacks of steam cans.

Two fixed steam flow monitors and a portable flow monitor were used for the steam flow measurements. One of the fixed steam monitors was connected to the orifice plate in the main steam line, and the other was connected to the orifice plate in the steam line feeding the Machnozzle. The portable steam flow monitor was used to measure steam flow to the Machnozzle, to monitor the steam flow to the individual stacks of cans, and to check the measurements made with the fixed steam flow monitors.

Each of the fixed, flow monitoring systems had four components: a transducer, a flow rate chart recorder, a totalizer, and a counter. The transducer measured the pressure drop across the orifice plate and converted the pressure drop into an electrical signal that was sent to the flow rate chart recorder and to the totalizer. The flow rate chart recorder plotted continuously steam flow rate, and the totalizer integrated flow rate over time and fed a signal into a counter which gave counts proportional to total flow. The installed recorders are shown in Figure 20. The fixed steam flow monitoring system used with the Machnozzle consisted of a Foxboro transducer, a Foxboro chart recorder, and a Foxboro totalizer. The other fixed steam flow monitoring system consisted of a Rosemont

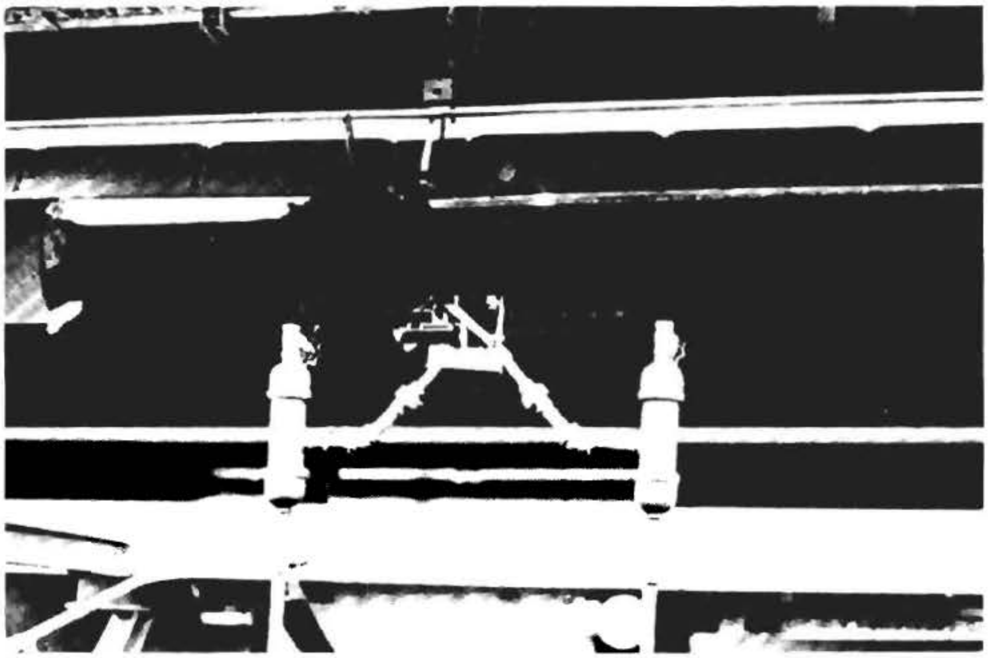


Figure 18 Main Header Orifice Plate Installation

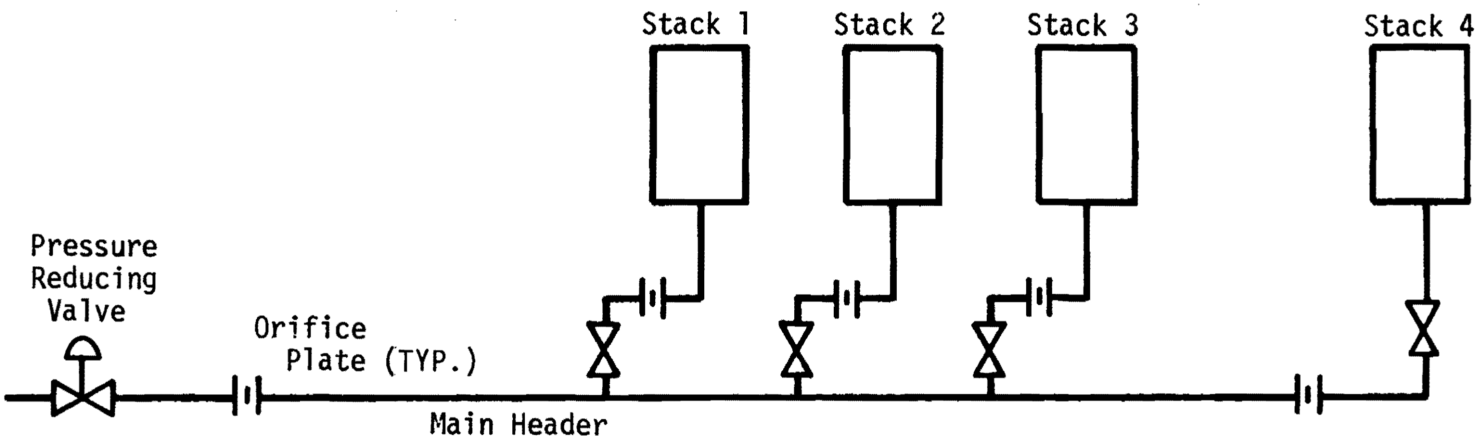


Figure 19 Schematic of Steam Can Stack Piping

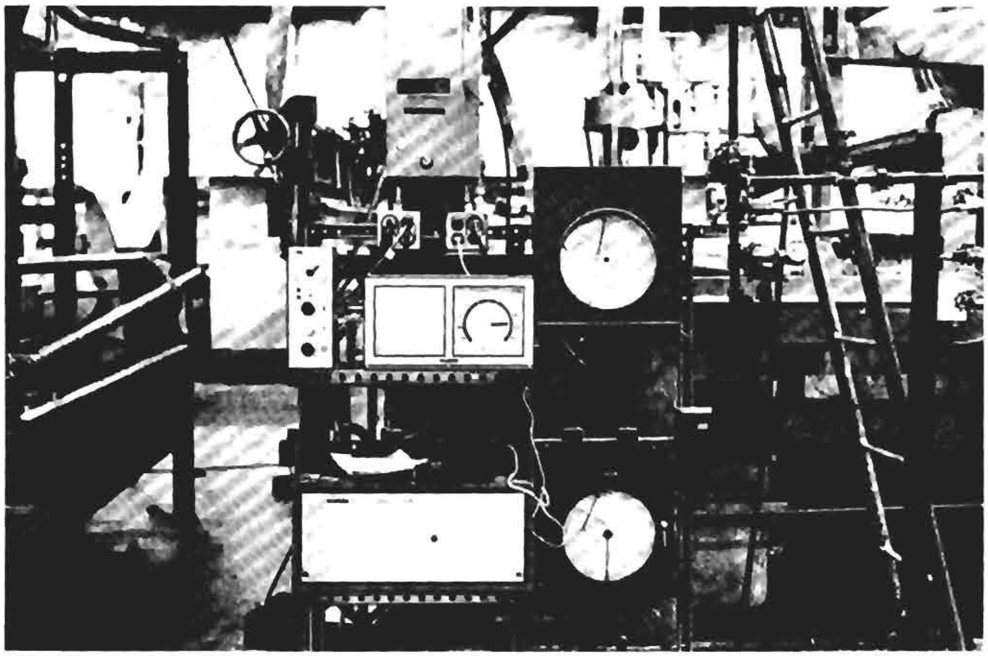


Figure 20 Fixed Steam Flow Recorders

Transducer and a Taylor chart recorder with a built-in totalizer.

The portable flow monitor, shown in Figure 21, was a TDI-100 Flow Monitor which was composed of a transducer unit and a computer unit. The transducer measured the pressure drop across the orifice plate, converted the pressure drop to an electrical signal, and sent the electrical signal to the computer unit. The computer unit computed the flow rate from the transducer signal and integrated the flow rate over time to give total flow. Both flow rate and total flow from the time metering began were continuously read with the TDI-100.

3.5 Experimental Plan

As initially planned, the in-plant demonstration was to be carried out in two phases. The first phase of testing was to produce extensive data on energy consumption, fabric regain, and the effect of the Machnozzle on product quality. The second phase was to produce long term, average energy consumption data and point up any day-to-day problems in the operation of a Machnozzle in a production environment.

The first phase of demonstration was conducted by Georgia Tech personnel with assistance from plant personnel and lasted approximately six weeks. Tests were run on five types of 43-inch, sheeting-weight goods (See Table 1). Each fabric was tested at two to four process speeds. Machnozzle supply pressures of 20 psig to 115 psig were investigated, and the number of steam can stacks used was varied whenever possible. The tests are summarized in Table 1.

The second phase of the demonstration to be carried out by plant personnel was not conducted due to limited quantities of 43-inch-wide fabric being processed. In the past, 43-inch-wide fabric was used to produce pillow cases. However, at the conclusion of Phase I, a new fabrication technique utilizing wider fabrics was being used. As a result, the volume of 43-inch-wide fabric being processed was insufficient for Phase II to be conducted using the 43.3-inch Machnozzle. However, the results of Phase I

Figure 21 TDI-100 Portable Steam Flow Monitor

Table 1 - Summary of Tests

Fabric Type	Process Speed (YPM)	Test Conditions
Textured 80/20 Polyester/cotton 2.94oz/yd^2	50	Control - 1ST* Machnozzle - 1ST Pressures (psig)-20,40,60,80,100
	75	Control - 1ST, 2ST, 3ST, and 4ST Machnozzle - 1ST Pressures (psig)-20,40,60,80,100 and 110
	100	Control - 2ST, 3ST, 4ST Machnozzle - 1ST Pressures (psig)-20,40,60,80,100
	125	Control - 2ST Machnozzle - 1st Pressures (psig) - 60, 80, 100
Muslin 65/35 Polyester/cotton 3.42oz/yd^2	75	Control - 2ST and 4ST Machnozzle - 1ST Pressures (psig)-40,60,80,100 2ST Pressures (psig)-100
	100	Control - 2ST, 3ST and 4ST Machnozzle - 1ST Pressures (psig)-20,40,60,80, and 100
	115	Control - 2ST, 3ST and 4ST Machnozzle - 2ST Pressures (psig)-20,40,60,80, and 100
	115**	Control - 2ST, 3ST and 4ST Machnozzle - 2ST Pressures (psig) 103 to 110

Table 1 (Continued)

Fabric Type	Process Speed (YPM)	Test Conditions
Percale 65/35 Polyester/cotton 3.41oz/yd^2	50	Control - 2ST Machnozzle - 2ST Pressures (psig) 80
	75	Control - 2ST, 3ST and 4ST Machnozzle - 1ST Pressures (psig) 20,40,60,80,100 and 115
100% Cotton 3.46oz/yd^2	70**	Control - 0ST Machnozzle - 0ST Pressures (psig) 40,60,80,100 and 110
Percale 50/50 Polyester/cotton 3.40oz/yd^2	50	Control - 1ST and 4ST Machnozzle - 1ST Pressures (psig)-40,60,80 and 100
	75	Control - 1ST, 2ST, 3ST and 4ST Machnozzle - 1ST Pressures (psig)-80 and 95
	80***	Control - 1ST Machnozzle - 1ST Pressures (psig)-40,60,80, and 95
	100***	Control - 1ST and 4ST Machnozzle - 1ST and 4 ST Pressures (psig)-60,80,90

*ST refers to a stack of ten steam cans
1ST means that one stack of cans was used during test,
2ST means that two stacks of cans were used during test, etc.
**No Shim in Machnozzle
***Rerun fabric (previously dried)

were sufficiently favorable that J.P. Stevens Company, Inc. was seriously considering further tests using a wider Machnozzle. Due to the length of time involved in purchasing and installing the Machnozzle and auxiliary equipment, results from further tests will not be included in the report. Results from future tests will be reported as they are available.

3.6 Results of Machnozzle Tests

Data were taken during the in-plant demonstration so that the effectiveness of the Machnozzle in removing moisture from fabrics could be determined. The primary parameters varied during the tests were fabric type, fabric speed, and Machnozzle supply pressure. The two responses monitored were regain and energy consumption. Regain is defined in Reference 5 as follows:

$$\text{Regain} = \frac{\text{Weight of Water in Fabric}}{\text{Bone Dry Fabric Weight}} \times 100\%.$$

The results of the tests are discussed in this section.

Regain - The effects of steam supply pressure, process speed, and fabric type on regain can be seen in Figures 22 through 28. Regain for control was the regain after the squeeze rolls (see Figure 9) and just before the Machnozzle. The amount of moisture removed by the Machozzle for a given condition was the difference between the regain for control and the regain measured directly after the Machnozzle.

The test results showed that the Machnozzle can substantially reduce the regain in sheeting-weight fabric. The regain after the squeeze rolls and just prior to the Machnozzle generally ranged from 75 to 90%. Typically, the Machnozzle reduced the regain of the fabric to approximately 20 to 35% at a steam supply pressure of 100 psig. Two exceptions were

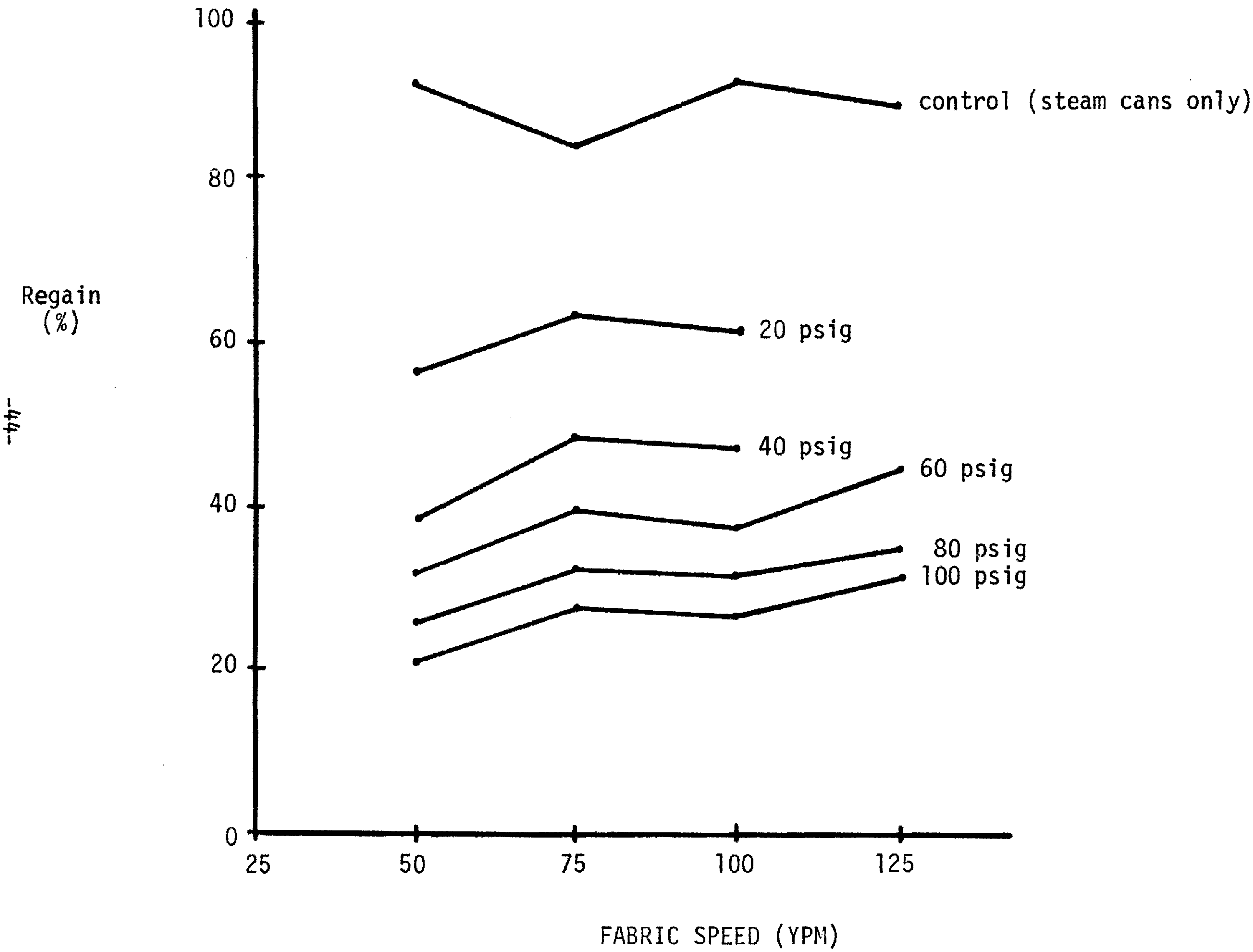


Figure 22 Regain versus Fabric Speed for 80/20 Textured Polyester/Cotton

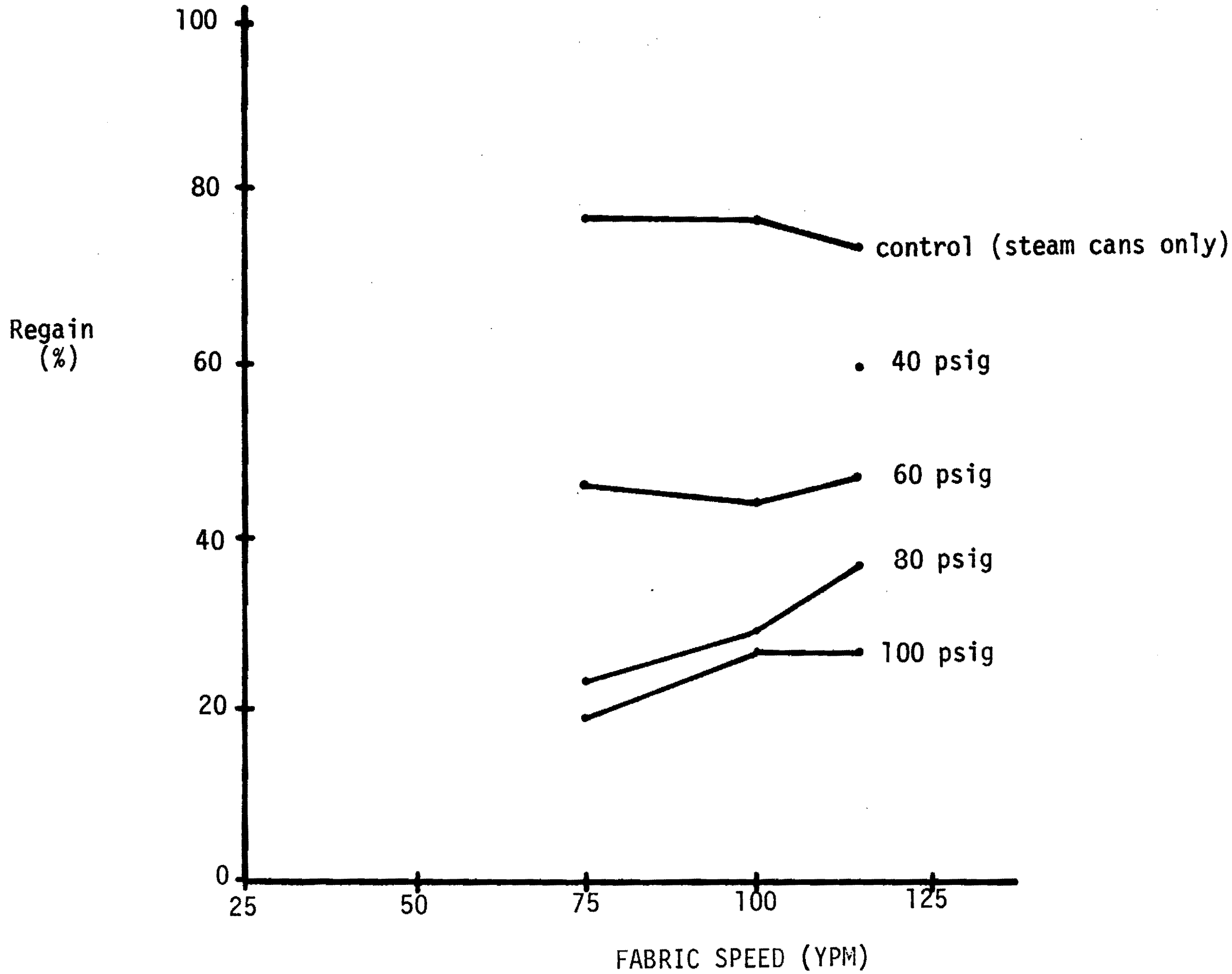


Figure 23 Regain versus Fabric Speed for 65/35 Polyester/Cotton Muslin

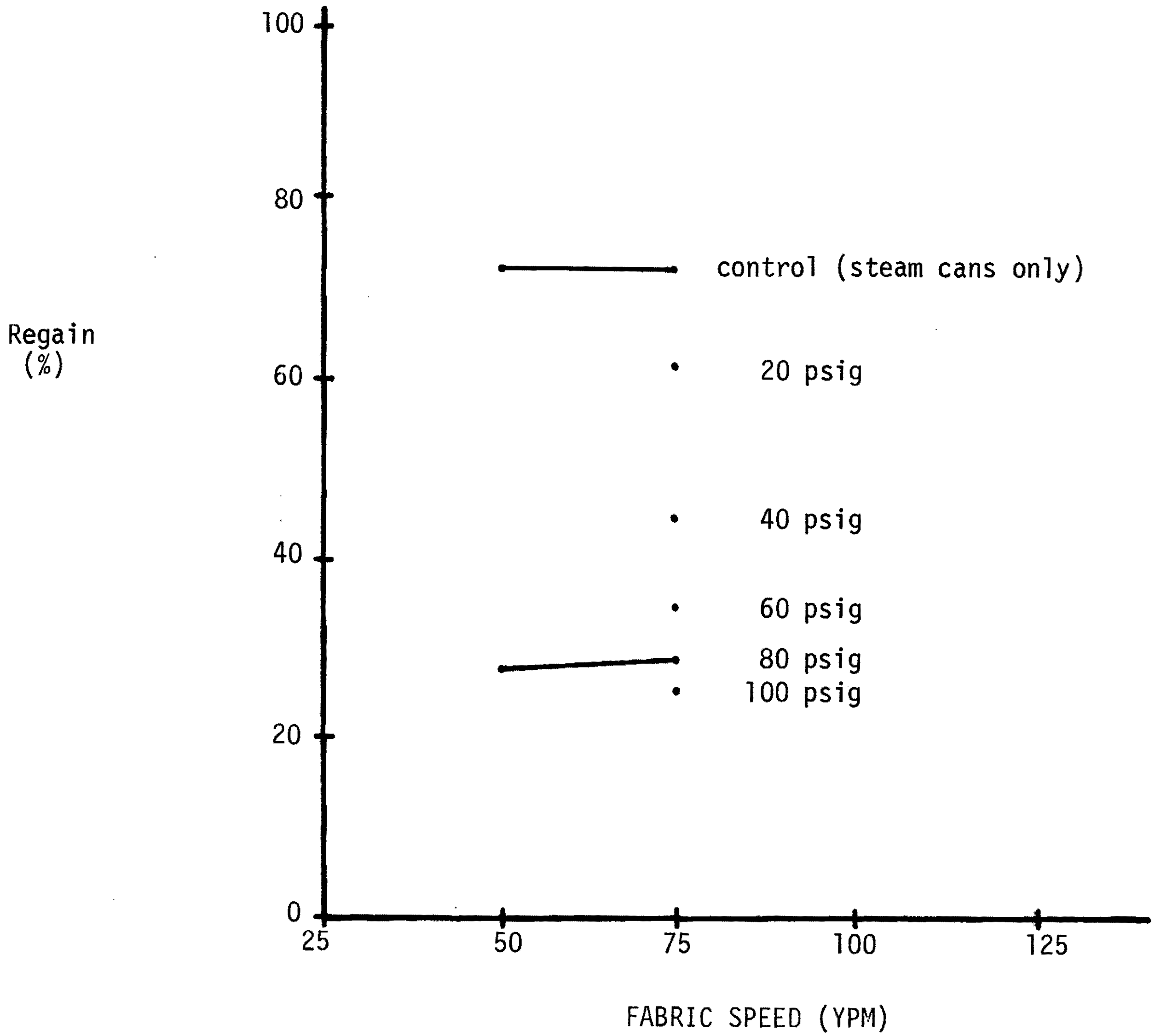


Figure 24 Regain versus Fabric Speed for 65/35 Polyester/Cotton Percale

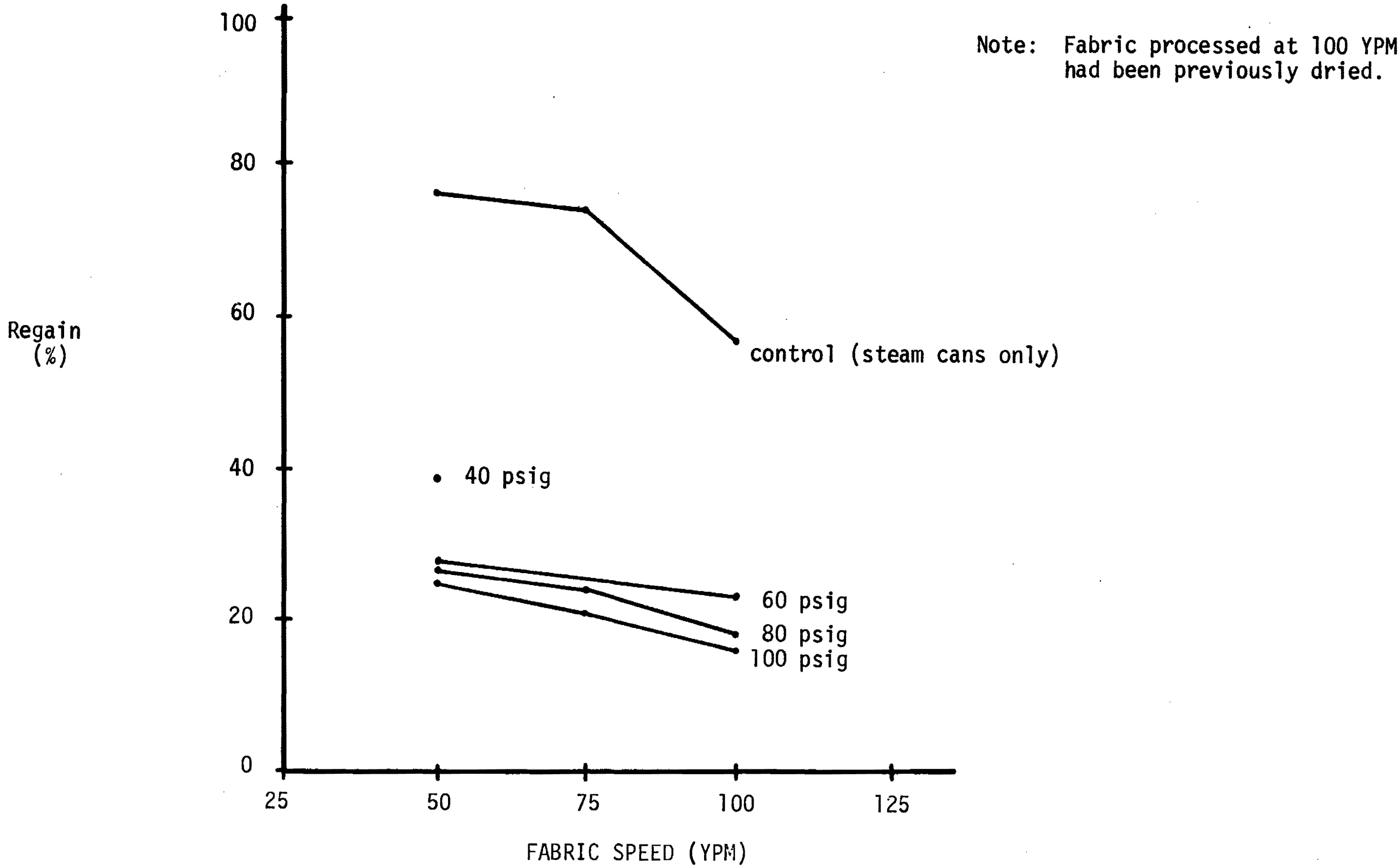


Figure 25 Regain versus Fabric Speed for 50/50 Polyester/Cotton Percale

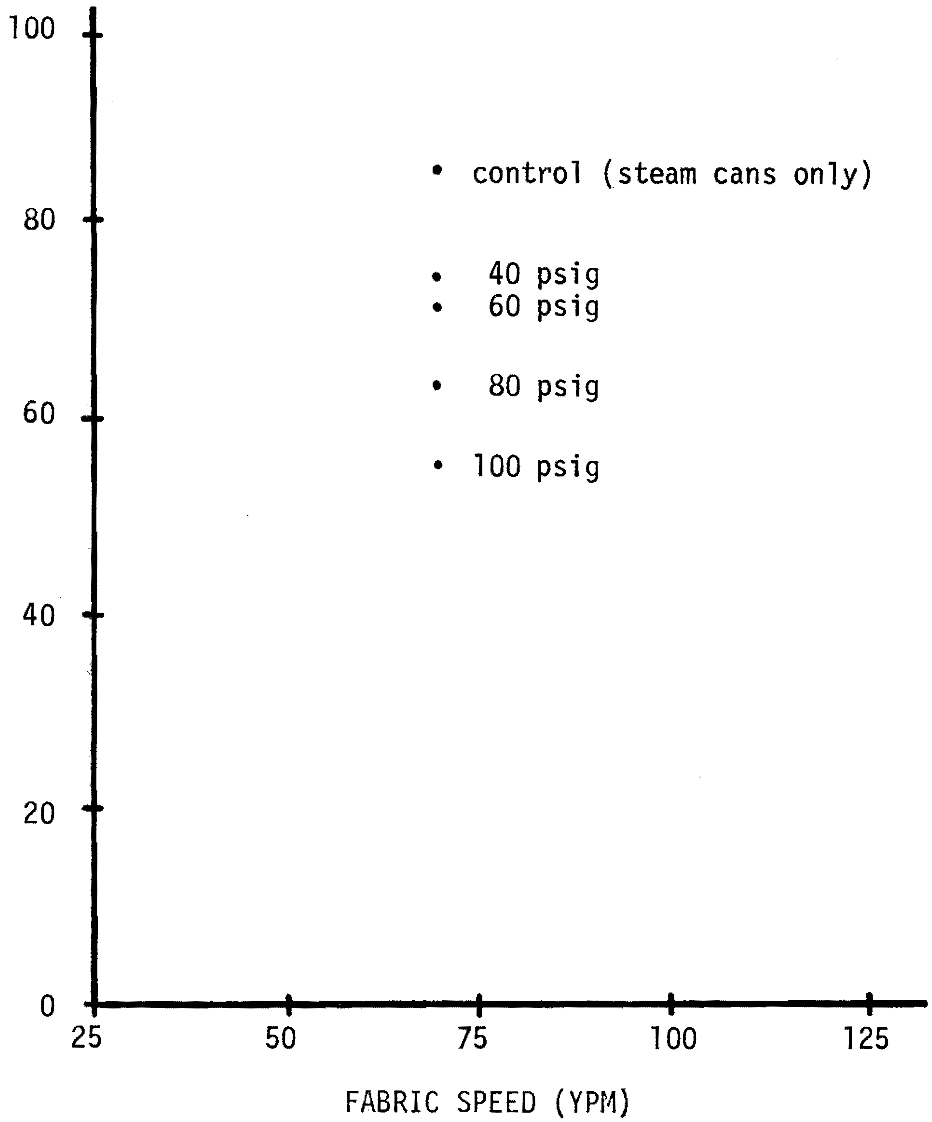


Figure 26 Regain versus Fabric Speed for 100% Cotton

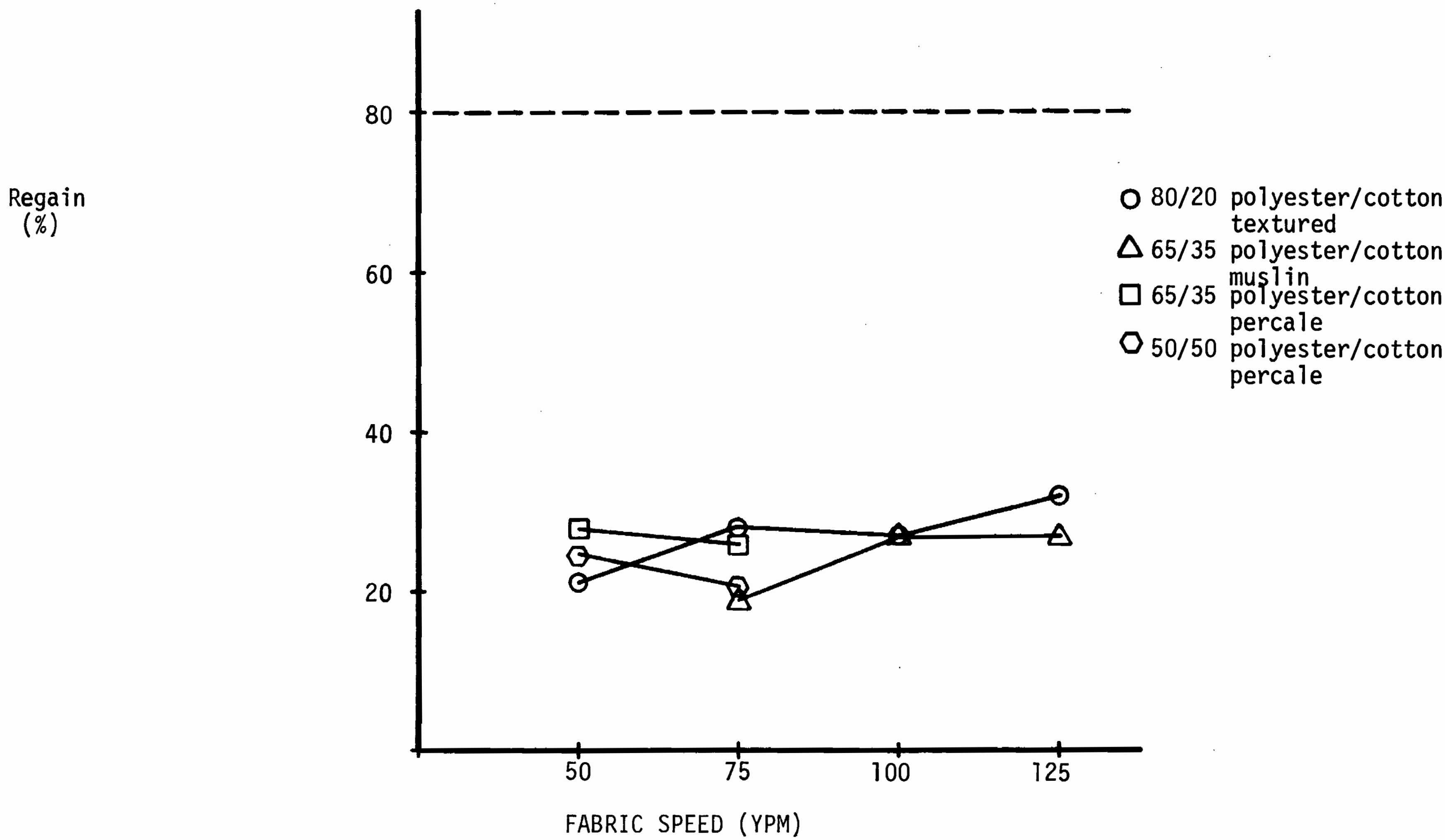


Figure 27 The Effect of Fabric Speed on Regain for a Steam Supply Pressure of 100 PSIG

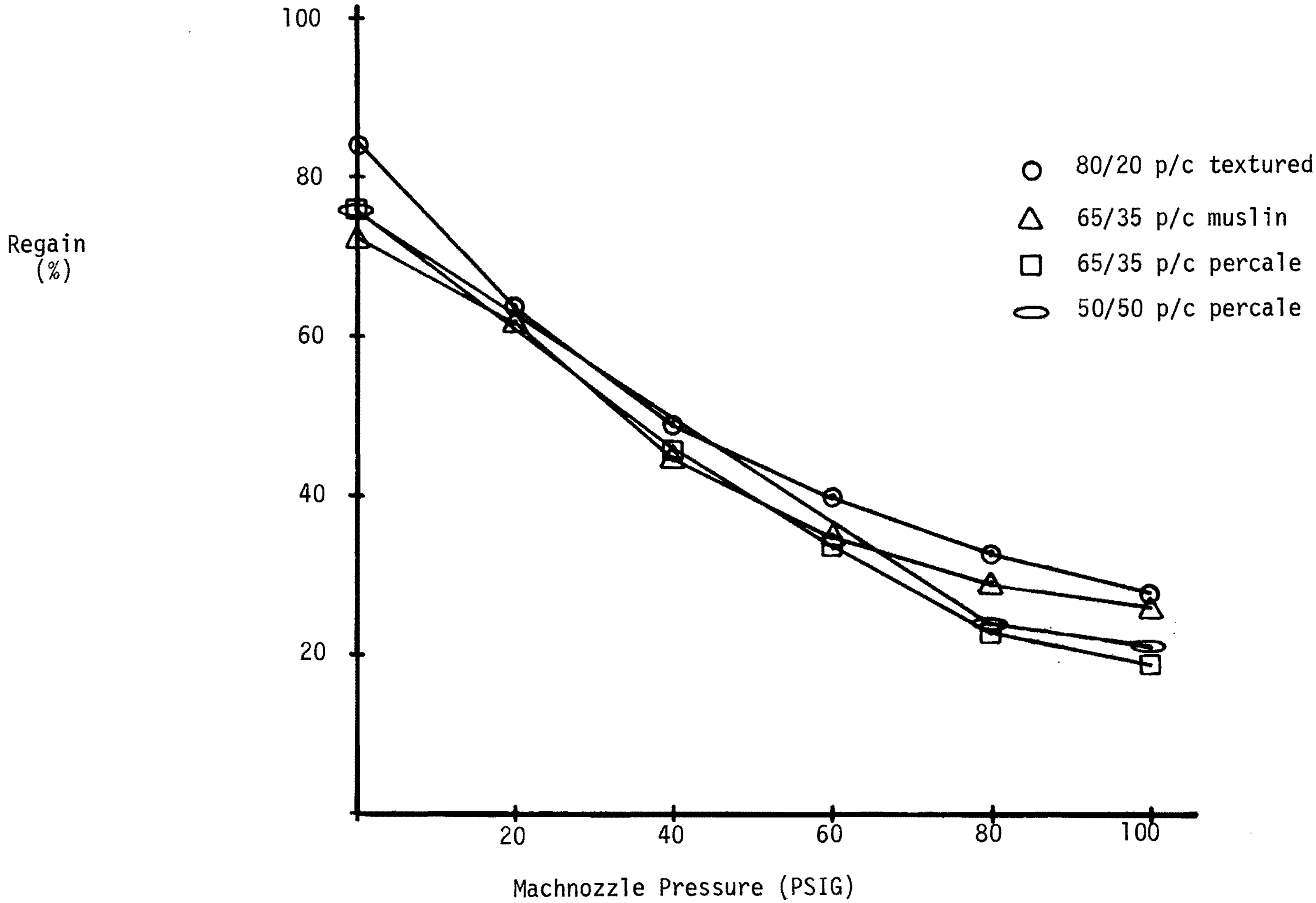


Figure 28 Regain versus Steam Supply Pressure at 75 YPM

reprocessed 50/50 polyester/cotton percale and 100% cotton fabric. The 50/50 polyester/cotton percale fabric tested at 80 and 100 YPM had been previously dried and is referred to in Table 1 as rerun goods. Due to limited quanities of 43-inch fabric being processed at the plant, 50/50 polyester/cotton percale fabric was not available for testing under normal operating conditions. The test results revealed that previously dried goods had different characteristics than fabric just prepared. Figure 25 shows that, for the rerun goods, the regain after the squeeze rolls and just prior to the Machnozzle was approximately 57% which was substantially lower than that for the fabric just prepared. Also, the regains for the various steam supply pressures were lower for the rerun goods. At a steam supply pressure of 100 psig and a process speed of 100 YPM, the regain of the rerun fabric was only 16%. Since the tests showed that previously dried goods had different characteristics than fabric just prepared, no further testing was performed on rerun goods.

Figure 26 shows that the Machnozzle reduced the regain of 100% cotton fabric to approximately 56% which is much higher (56% versus 36%) than obtained during the pilot-scale study. The results shown for the 100% cotton fabric were obtained during the initial sequence of tests conducted during the in-plant demonstration. The regains for all the fabrics tested during the initial sequence were higher than those obtained during the pilot-scale study. Also, the steam flow rate per linear inch of nozzle was lower than that for the 16-inch Machnozzle used during the pilot-scale studies, indicating the slot width of the 43-inch Machnozzle was narrower than that of the 16-inch Machnozzle. A 0.002-inch shim was used to increase the slot width of the 43-inch Machnozzle. After the insertion of the shim, the regains obtained with the 43-inch Machnozzle were comparable to those obtained during the pilot-scale study. Further tests with 100% cotton fabric were not run because of the unavailability of 100% cotton fabric.

The effect of fabric speed on regain directly after the Machnozzle is illustrated in Figure 27 for four types of sheeting-weight fabrics. Regain increased slightly as fabric speed was increased. For example, at a steam supply pressure of 100 psig, the regain of 80/20 textured polyester/cotton fabric increased from 21 to 32% as fabric speed was increased from 50 to 125 YPM. Even though regain was slightly higher at the higher fabric speeds, the Machnozzle was more energy efficient at the higher fabric speeds. This occurred because productivity increased linearly with fabric speed, but steam consumption by the Machnozzle was almost independent of fabric speed.

Increasing steam supply pressure had similar effects on the regain for all of the fabrics tested, as shown in Figure 28. Increasing steam supply pressure caused regain to decrease. Regain decreased steadily as pressure was increased from 0 to 80 psig. However, the incremental change in regain with incremental change in steam supply pressure decreased with increasing pressure. For example, when steam supply pressure was increased from 80 to 100 psig for 65/35 polyester/cotton muslin fabric running at 100 YPM, the reduction in regain was only 2% (27% versus 29%). Since steam consumption increased with supply pressure, the optimal pressure to operate the Machnozzle depends on various process parameters such as fabric type and process speed.

Energy Consumption

The energy efficiency of the Machnozzle was measured in terms of pounds of steam consumed per pound of water removed (lbs/lbw). The energy requirements of the Machnozzle are compared with those for steam cans in Figures 29 through 32. The steam consumption of the Machnozzle was substantially lower than that of steam cans. Typically the energy consumption of the Machnozzle ranged from approximately 0.5 to 1.1 lbs/lbw, depending on process speed and steam supply pressure. The steam cans typically required from 1.5 to 2.3 lbs/lbw. The steam consumption data on the Machnozzle given above were based on no energy recovered frm the steam passing through the fabric. The results of condenser tests (See Section

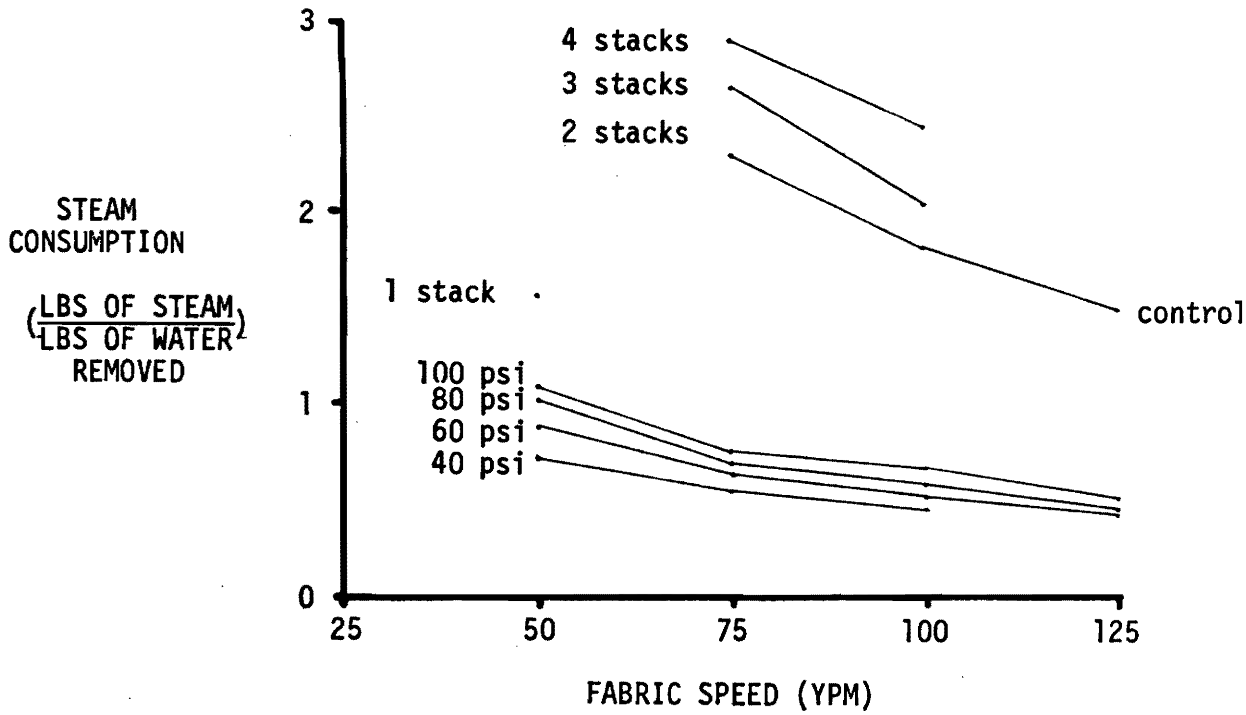


Figure 29 Steam Consumption of Machnozzle and Steam Cans versus Fabric Speed for 80/20 Textured Polyester/Cotton

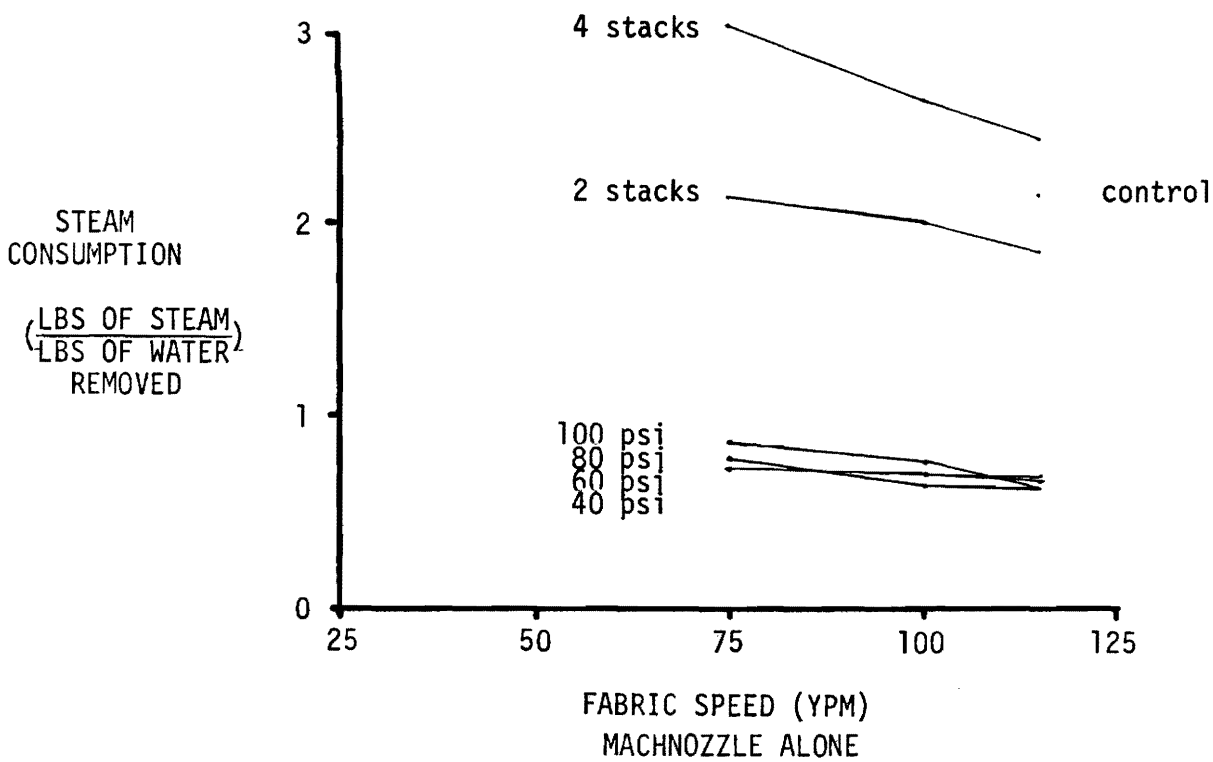


Figure 30 Steam Consumption of Machnozzle and Steam Cans versus Fabric Speed for 65/35 Polyester/Cotton Muslin

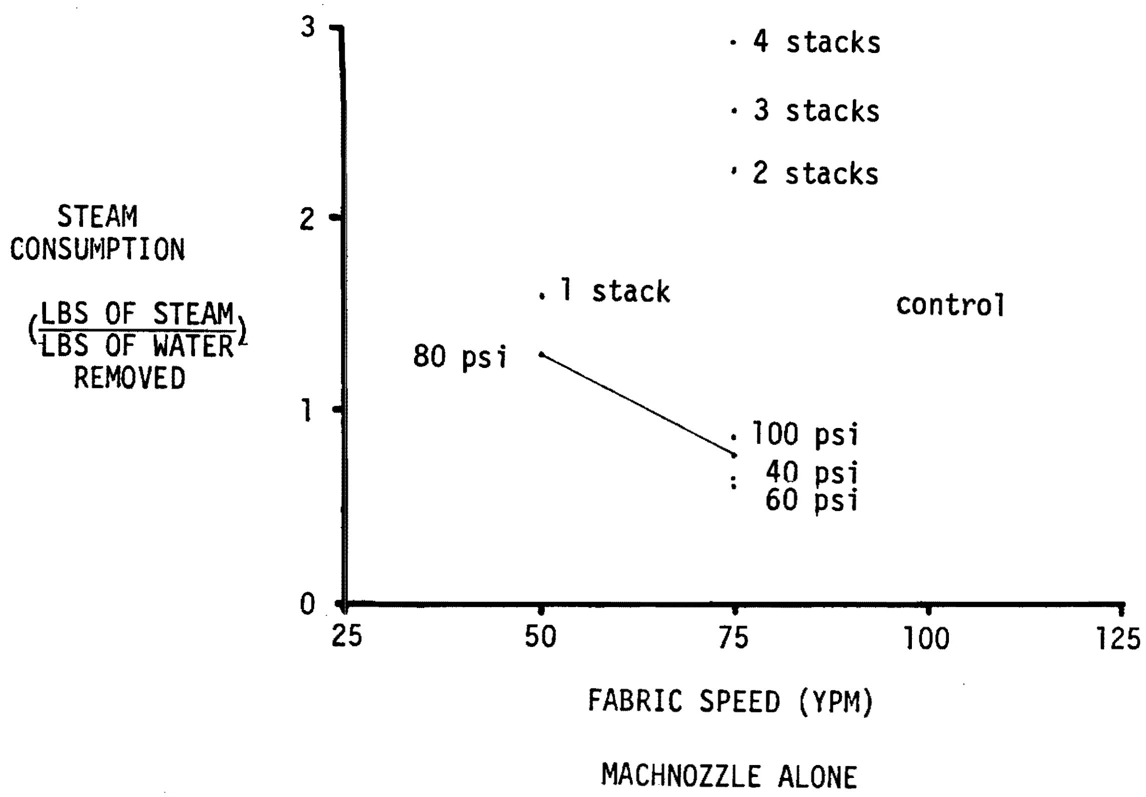


Figure 31 Steam Consumption of Machnozzle and Steam Cans versus Fabric Speed for 65/35 Polyester/Cotton Percale

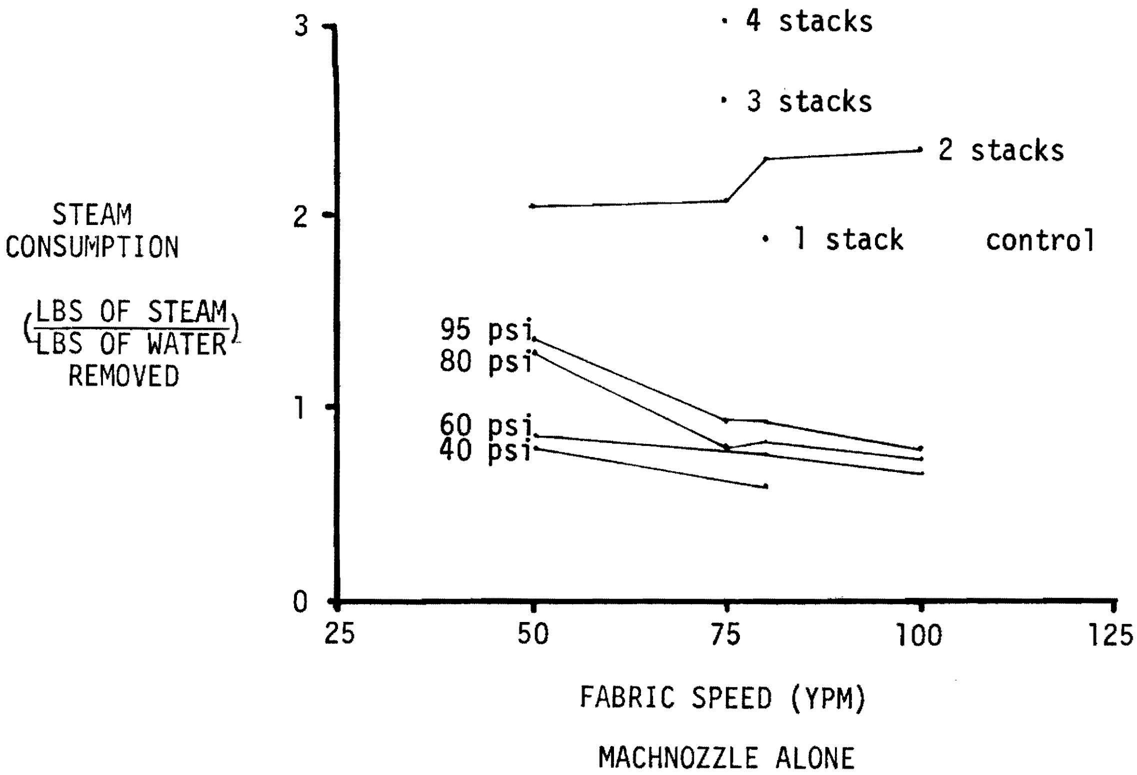


Figure 32 Steam Consumption of Machnozzle and Steam Cans versus Fabric Speed for 50/50 Polyester/Cotton Percale

3.7) indicated that approximately 65% of the thermal energy of the steam entering the Machnozzle can be recovered. Assuming an energy recovery of 65%, the steam consumption of the Machnozzle ranged from 0.2 to 0.4 lbs/lbw.

The steam consumption (lbs/lbw) of the Machnozzle decreased as fabric speed was increased. For example (see Figure 29), consider the variation of Machnozzle steam consumption for 80/20 textured polyester/cotton fabric and a steam supply pressure of 100 psig. When fabric speed was increased from 50 to 75, 100, and 125 YPM, steam consumption decreased from 1.09 to 0.76, 0.66, and 0.51 lbs/lbw, respectively. Similar results were obtained for all four types of fabrics tested at different fabric speeds. Steam consumption (lbs/lbw) decreased as fabric speed increased even though lower regains were obtained at lower fabric speed. This occurred because as fabric speed was increased, more fabric per unit time was processed by the Machnozzle. As a result more water per unit time was removed. Since the rate of steam used by the Machnozzle (lbs/lbw) varied very little with fabric speed, the energy efficiency of the Machnozzle improved with increasing fabric speed.

As Machnozzle supply pressure was increased, steam consumption (lbs/lbw) generally increased slightly. For example, when the steam supply pressure was increased from 20 to 40, 60, 80, and 100 psig, for 80/20 textured polyester/cotton fabric processed at 100 YPM (See Figure 29), steam consumption for the respective pressures were: 0.40, 0.44, 0.51, 0.58, and 0.66 lbs/lbw. However moisture removal improved with increasing steam supply pressure. As a result, less water was left in the fabric to be removed by steam cans. The optimal steam supply pressure depends on fabric type, fabric speed, and economic factors. Thus, determining optimal economical operating steam pressure required an incremental analysis which is discussed in Section 4.

3.7 Results of Condenser Tests

Condenser testing was begun with the initial Machnozzle performance runs. The initial performance of the condenser was far below expectation. Therefore, considerable development was done on the condenser during the course of the test program. As a result, limited data were taken on the condenser in its final configuration; however, sufficient testing was performed to show that a significant part of the thermal energy can be recovered. The condenser development resulted in the identification of a number of design considerations for such a condenser system. These are discussed in Section 6.

The condenser was tested while running 65/35 polyester/cotton muslin on the finishing range at 100 YPM. The Machnozzle was operated at two steam pressures, 60 and 80 psig. The cooling water flow rate was varied from 7.6 to 13.1 gpm for steam flow rates ranging from 410 to 460 lbs/hr. The resulting hot water temperatures ranged from 117 to 164°F. The percentage of steam energy recovered ranged from 53 to 63%. A 196 to 205°F wastewater stream was also generated which included the water, lint, and impurities blown out of the fabric. This was generated at a rate of about 1 to 1-1/2 gpm. The results of one condenser test are presented in Figure 33. The results of the condenser test are summarized in Appendix C.

3.8 Quality Assessments

Tests were made on fabrics processed with the Machnozzle to determine whether the fabric properties differed from those of conventionally processed fabrics. The fabric properties most likely to be altered when the Machnozzle is used are as follows:

1. fabric color,
2. air permeability, and
3. pilling.

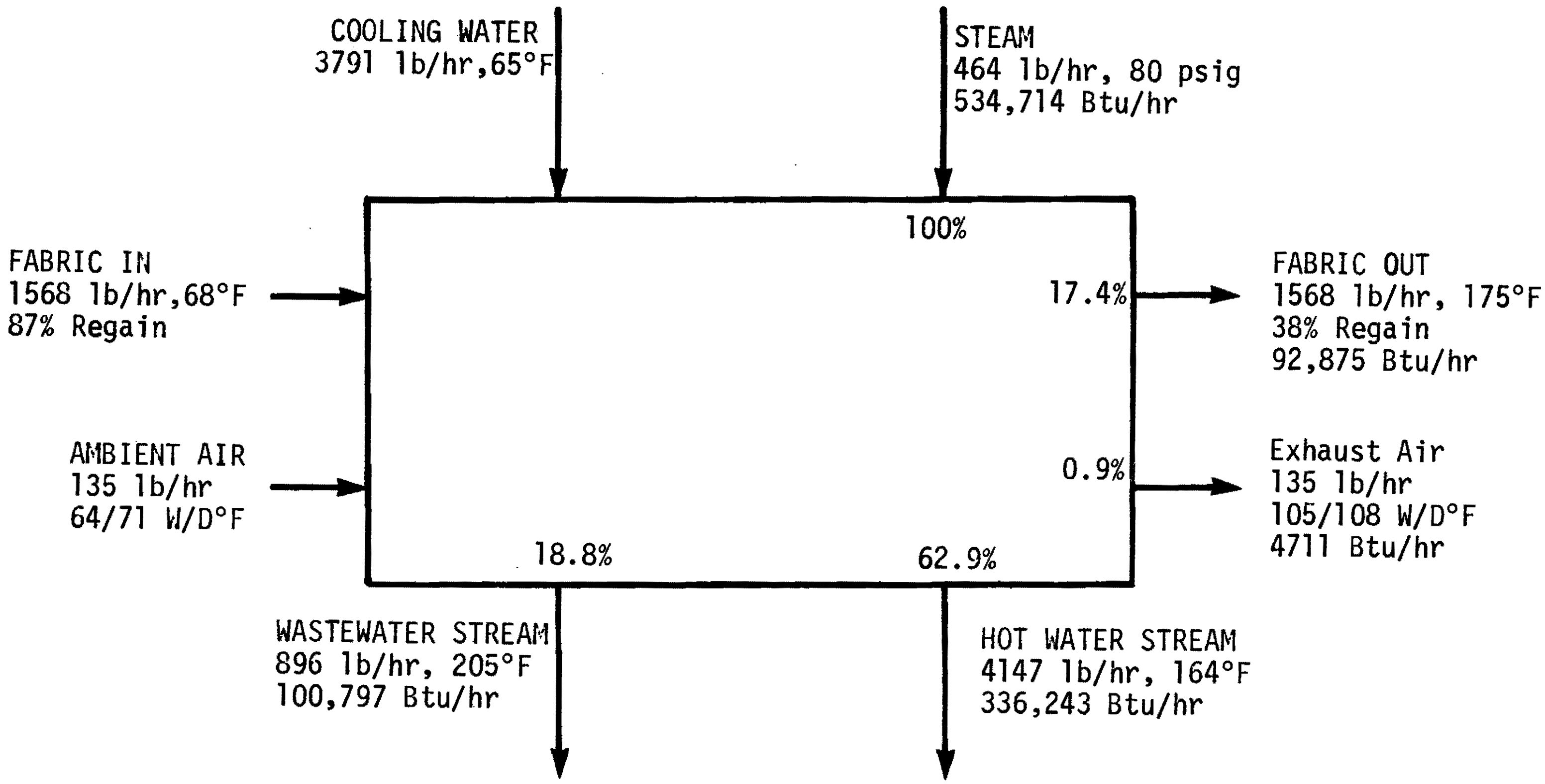


Figure 33 Mass and Energy Balance for the Condenser

The action of high pressure steam from the Machnozzle on a fabric could conceivably alter the fabric cover and thereby its air permeability. In addition, the action of the steam could result in fabrics having more or less loose hairs than before processing depending on whether loose hair are removed or produced by the action of the steam. The pilling behavior of the fabrics will depend, in part, on the concentration of hairs anchored loosely in the fabric structure.

Measurements of color, air permeability, and pilling were made on selected fabrics to show the effects of the following process variables:

1. fabric speed,
2. Machnozzle,
3. steam pressure to the Machnozzle,
4. type of fabric (fiber content and fabric construction).

In addition to these measurements, some fabrics were examined microscopically to determine whether fabrics processed with the Machnozzle differed visually from those processed conventionally.

The color measurements were made using the Applied Color Science 400 Color Computer System. One of the concerns in this work was the effect of the Machnozzle on the color of fabrics. Since all of the fabrics were in an uncolored state, whiteness values, W, were calculated from the spectrophotometric data. The formula used was as follows:

$$W = Y + a (x_n - x) + b (y_n - y)$$

where x_n and y_n are the chromaticity coordinates of a barium sulfate sample measured with the same calibration of the photometer as used for the measurement of x and y of the sample, a and b are coefficients, and Y is the tristimulus value. For CIE 1964 observer, $x_n = 0.3138$, $y_n = 0.3310$, a = 800, and b = 1700.

Table 2 includes the whiteness values for selected control samples and samples procesed with the Machnozzle. The data showed that the Machnozzle had no effect on the whiteness of the fabrics.

Air permeability data for some of the same fabrics are also included in Table 2. The method used to obtain these data was ASTM D 737-75. Five measurements of the air permeability were made with the fabric face-up in the instrument and five with be fabric face down. There was no difference in air permeability as a function of the direction in which the air is flowing. In addition, the effect of the Machnozzle on air permeability was insignificant.

The pilling resistance of selected fabrics was determined using the random tumble pilling tester method, ASTM D 3512-76. The objective was to determine whether fabrics processed conventionally differed from those processed with the use of the Machnozzle. The times of tumbling were 30 minutes and 60 minutes. The results which are shown in Table 3 indicated that the Machnozzle did not alter the pilling characteristics of the fabrics.

Microscopic examinations of fabrics conventionally processed and of fabrics processed with the Machnozzle were made. No difference between these fabrics was apparent.

Table 2
Results of Whiteness and Air Permeability Tests

Type Fabric	Fabric No.	Fabric Processing Speed (yd/min)	Machnozzle Pressure (PSIG)	Whiteness (W)	Air Permeability* ($ft^3/ft^2/min$) Face Up	Face Down
80/20 Polyester/ Cotton	6-26	125	100	86	191	187
	6-26	125	60	86	200	187
	14-15	100	Control**	82	174	169
	14-20	100	100	83	185	196
	14-18	100	20	81	167	172
	10-12	75	Control**	84	-	-
	10-11	75	100	82	156	166
	10-10	75	20	83		
	14-23	50	Control**	85	163	165
	14-22	50	80	81	182	188
	14-19	50	40	82	160	164
65/35 Polyester/ Cotton Muslin	4-27	115	Control**	86	118	113
	4-28	115	103-110	86	-	-
	11-40	115	Control**	76	149	150
	11-36	115	100	77	139	136
	11-39	115	40	76	132	129
	15-64	100	Control**	83	143	153
	15-63	100	80	82	134	131
	15-65	100	40	80	137	132
65/35 Polyester/ Cotton Percale	12-50	75	Control**	83	114	115
	12-52	75	100	84	119	125
	12-47	75	20	83	120	111
	12-44	50	80	81	122	125

Table 2 (Continued)

Type Fabric	Fabric No.	Fabric Processing Speed (yd/min)	Machnozzle Pressure (PSIG)	Whiteness (W)	Air Permeability* ($ft^3/ft^2/min$) Face Up	Face Down
50/50 Polyester/ Cotton Percale	7-32	100	Control**	86	96	100
	7-31	100	90	84	-	-
	7-33	100	60	87	-	-
	8-6	80	Control**	84	141	146
	8-1	80	Control**	89	124	119
	8-5	80	80	87	-	-
	8-2	80	20	85	-	-
	13-13	75	Control**	82	-	-
	13-14	75	Control**	78	-	-
	13-59	75	95	83	171	156
	13-54	50	Control**	81	128	126
	13-60	50	Control**	80	147	141
	13-58	50	100	81	132	134
	13-55	50	40	80	123	125
100% Cotton	5-43	70	Control**	82	70	75
	5-41	70	109	81	83	84
	5-42	70	40	79	78	77

*Air Permeability - cubic feet of air per square foot per minute at 30" of mercury, 70°F, 65% relative humidity.

**Control - Machnozzle not used.

Table 3
Pilling Resistance - Random Tumble
Pilling Tester Method ASTM D 3512-76

Sample Description	Sample No.		Pilling Rating* 30 min.	60 min.
65/35 Polyester/cotton muslin	15-64	Control	5	5
	15-63	With Machnozzle	5	5
65/35 Polyester/cotton percale	12-50	Control	5	5
	12-51	With Machnozzle	5	3-4
50/50 Polyester/cotton percale	8-1	Control	5	5
	8-5	With Machnozzle	5	5
100% Cotton	5-43	Control	5	5
	5-41	With Machnozzle	5	5

Pilling Rating Scale
5 no pilling
4 slight pilling
3 moderate pilling
2 severe pilling
1 very severe pilling

4. ECONOMIC ANALYSIS

An economic analysis of the Machnozzle as a predrying device was conducted based on the measured performance of the Machnozzle and several financial assumptions. The economic attractiveness of the Machnozzle was studied over a range of operating conditions and fuel prices. Two sets of equipment costs were used. The analysis indicated that the Machnozzle is an attractive investment for most of the cases studied. The Machnozzle and condenser showed simple paybacks as short as 2 months. The details of the economic analysis methodology and results are discussed in this section.

Performance Data and Financial Assumptions - The performance data, generated during the testing program, were compiled and used as an input to the economic analysis. The compiled data are included in Appendix D. An average steam, mass-flow rate was used for each of the steam supply pressures 20, 40, 60, 80 and 100 psig since the flow rate was almost independent of fabric type and speed. Fabric, mass-flow rates were calculated for 120-inch-wide fabric weighing 3.41 oz/yd^2. Average values of moisture reduction were used for each fabric speed and steam supply pressure since the Machnozzle performance was similar for all of the fabrics tested except 100% cotton. The alternative drying technique was assumed to be steam dryer cans requiring 1.5 pounds of steam per pound of water removed. The condenser was assumed to recover 65% of the energy contained in the steam as hot water. The steam savings resulting from the Machnozzle and Machnozzle with condenser were computed for each fabric speed and steam supply pressure. The optimum steam supply pressure was then identified for each fabric speed; both with and without the condenser. The energy savings for the optimum steam supply pressures, tabulated in Table 4, were used for the economic analysis.

It should be noted that the computation resulted in an optimum steam supply pressure of 100 psig for each of the five fabric speeds when using the condenser. This occurred because the computation assumed hot water energy to be equivalent in value to steam energy. The hot water energy

Table 4
Optimum Steam Supply Pressures
From 43.3-Inch Machnozzle Data

		Without Condenser		With Condenser	
Fabric Speed (YPM)	Fabric Mass Flow Rate (LBS/HR)	Optimum Steam Supply Pressure (PSIG)	Resulting Steam Savings (LBS/HR)	Optimum Steam Supply Pressure (PSIG)	Resulting Steam Savings (LBS/HR)
50	764	40	182	100	408
75	1146	80	398	100	690
100	1527	80	563	100	912
115	1756	100	728	100	1077
125	1909	80	701	100	1043

could be discounted to reflect a difference in value.

The economic analysis required a number of cost and financial assumptions to be made. These assumptions are given in Table 5. The assumptions are discussed below.

It was assumed that the Machnozzle installation was a retrofit on existing steam dryer cans. Therefore, no capital savings would result from installing the Machnozzle in place of steam dryer cans. Two sets of equipment costs for a 120-inch Machnozzle system were used in the analysis (See Appendix D). One estimate was based on costs incurred by Georgia Tech during the research project and estimates made by the researchers based on the experience gained during the project. The other cost estimate was based on equipment quotations made to J.P. Stevens and Co., Inc. by Brugman's U.S. representative.

The maintenance requirement was estimated to be $1000 in the first year. This expense was inflated at 10% per year over the life of the system.

The analysis includes the following income tax effects: the investment tax credit, income tax on fuel savings, income tax savings resulting from maintenance and interest expenses, and income tax savings resulting from depreciation. The equipment qualifies for the regular 10% investment tax credit. Part or all of the system may qualify for an additional 15% business energy investment credit. This would serve to make the system look more favorable. The equipment was depreciated over seven years using double-declining-balance depreciation. The total equipment cost was financed at an interest rate of 15% per year.

Three fuel prices; 3.50, 5.00, and 6.50 $\$/10^6$ Btu; were used in the analysis. These values are in line with current boiler fuel prices in the Southeast. The fuel escalation rate was assumed to be 20% per year over the life of the equipment. The assumption was based on historical price trends from the Producer Price Index from the Bureau of Labor Statistics (Reference 9). For the period from 1973 through the end of 1980, both natural gas and petroleum prices have risen at an average rate greater than

Table 5
Cost and Financial Assumptions

Cost of Machnozzle & Mounting Fixtures	\$12302, \$16981
Cost of Condenser	\$ 5185, \$22309
Annual Maintenance Cost	\$1000
Investment Tax Credit	10%
Incremental Tax Rate	48%
Fuel Price	3.50, 5.00, 6.50 \$/10^6 Btu
Fuel Escalation Rate	20%
Boiler Efficiency	72%
Inflation Rate	10%
Interest Rate	15%
Discount Rate	15%
Depreciation	Double Declining Balance
Annual Machine Operation	6900 hrs.
Machine Width	120 inches

25% per year.

The analysis included calculation of the Net Present Value, Benefit-to-Cost Ratio, and Simple Payback for each of the cases. A 15% discount rate was used to discount the annual cash flows over the system tax life to their present value. The present values of the cash flows were used to compute Net Present Value and Benefit-to-Cost Ratio.

Methodology - The three calculations; Net Present Value, Benefit-to-Cost Ratio, and Simple Payback; were based on the annual cash flows from the system. The annual cash flow in the first year is given below.

Annual Cash Flow = Investment Tax Credit + (1-Tax Rate) x Fuel Cost Savings - (1-Tax Rate) x Maintenance Cost - Principal Payment + (Tax Rate) x Depreciation - (1-Tax Rate) x Interest Payment.

Summation formulas were derived to compute the present value of each of the cash flow strings. A mini-computer was used to make the calculations. The Net Present Value was the present value of the annual cash flows. The Benefit-to-Cost Ratio was the present value of each of the cash flow strings, excluding the loan payments, divided by the initial system cost. The equations and computer program are included in Appendix D. The simple payback was also computed on an after-tax basis. A computer program was used to calculate how long it would take the system benefits minus the maintenance cost to equal the initial cost of the system. The cash flows were not discounted. This computer program is also included in Appendix D.

Results - The economic analysis showed that for the given assumptions, in most of the 60 cases, the Machnozzle was a favorable investment. The results for the twelve cases at a fabric speed of 100 YPM are given in Table 6. The results of all sixty cases are given in Appendix D.

All sixty cases had a positive Net Present Value. The Benefit-to-Cost

Table 6
Economic Analysis Results For A
120-Inch Machnozzle At A Fabric Speed
of 100 YPM

Fuel Price ($\$/10^6$Btu)	Equipment Cost Estimate	Without Condenser NPV ($)	Without Condenser B/C	Without Condenser Simple Payback (YR)	With Condenser NPV ($)	With Condenser B/C	With Condenser Simple Payback (YR)
3.50	Low	252,932	21.56	.38	412,535	24.59	.33
3.50	High	251,175	15.79	.51	404,348	11.29	.70
5.00	Low	364,469	30.63	.27	593,214	34.92	.23
5.00	High	362,712	22.36	.36	585,026	15.89	.50
6.50	Low	476,542	39.74	.21	774,760	45.30	.18
6.50	High	474,785	28.96	.28	766,573	20.51	.39

Ratios ranged from 5.4 to 53.4. The Simple Paybacks ranged from 2 to 17 months. In all cases, the Net Present Value was higher with the condenser. In the cases which used the lower equipment cost estimate, the Benefit-to-Cost Ratios were higher with the condenser. In the cases with the higher equipment cost estimate, the Benefit-to-Cost Ratios were higher without the condenser. This was due to the relative costs of the Machnozzle and condenser. The cases with the higher fabric speeds were more favorable due to their higher steam savings rates.

5. DISSEMINATION OF RESULTS

The details of the demonstration and the end results will be widely disseminated to the industry. The Georgia Tech researchers are active in a number of annual short courses and workshops on which the industry is dependent for introduction to energy related technology. A presentation on the demonstration project and the preliminary results of the project was made at a Clemson University energy conservation short course on March 25, 1981. The researchers will also publish the results in widely read periodicals and trade magazines. An article on the results of the pilot-scale study of the Machnozzle was published in the May, 1981, edition of American Dyestuff Reporter. A presentation of the results of the in-plant demonstration was made at the ASME Textiles Industries Conference at Raleigh, North Carolina, on October 13 and 14, 1981. Trade organizations, such as the American Association of Textile Chemists and Colorists, the American Textile Manufacturing Institute, the American Society of Mechanical Engineers, and the various state textile manufacturers groups will also be utilized to disperse the demonstration results. Georgia Tech has excellent rapport with these various media and organizations through the Engineering Experiment Station's industry-related programs, through the School of Textile Engineering, and from close cooperation on related energy projects.

6. CONCLUSIONS AND RECOMMENDATIONS

The results of the in-plant demonstration of the Machnozzle as a predrying device for sheeting weight fabrics were very favorable. The moisture removing ability of the Machnozzle was demonstrated on a commercial scale. The energy efficiency of the Machnozzle was superior to that of steam cans. There were no deleterious effects on product quality. Finally, the Machnozzle appears to be an attractive financial investment.

The demonstration program identified several important design considerations for the equipment associated with the Machnozzle. Pipe scale must be kept out of the steam delivered to the Machnozzle. All piping downstream of the centrifugal separator should be of stainless steel or brass.

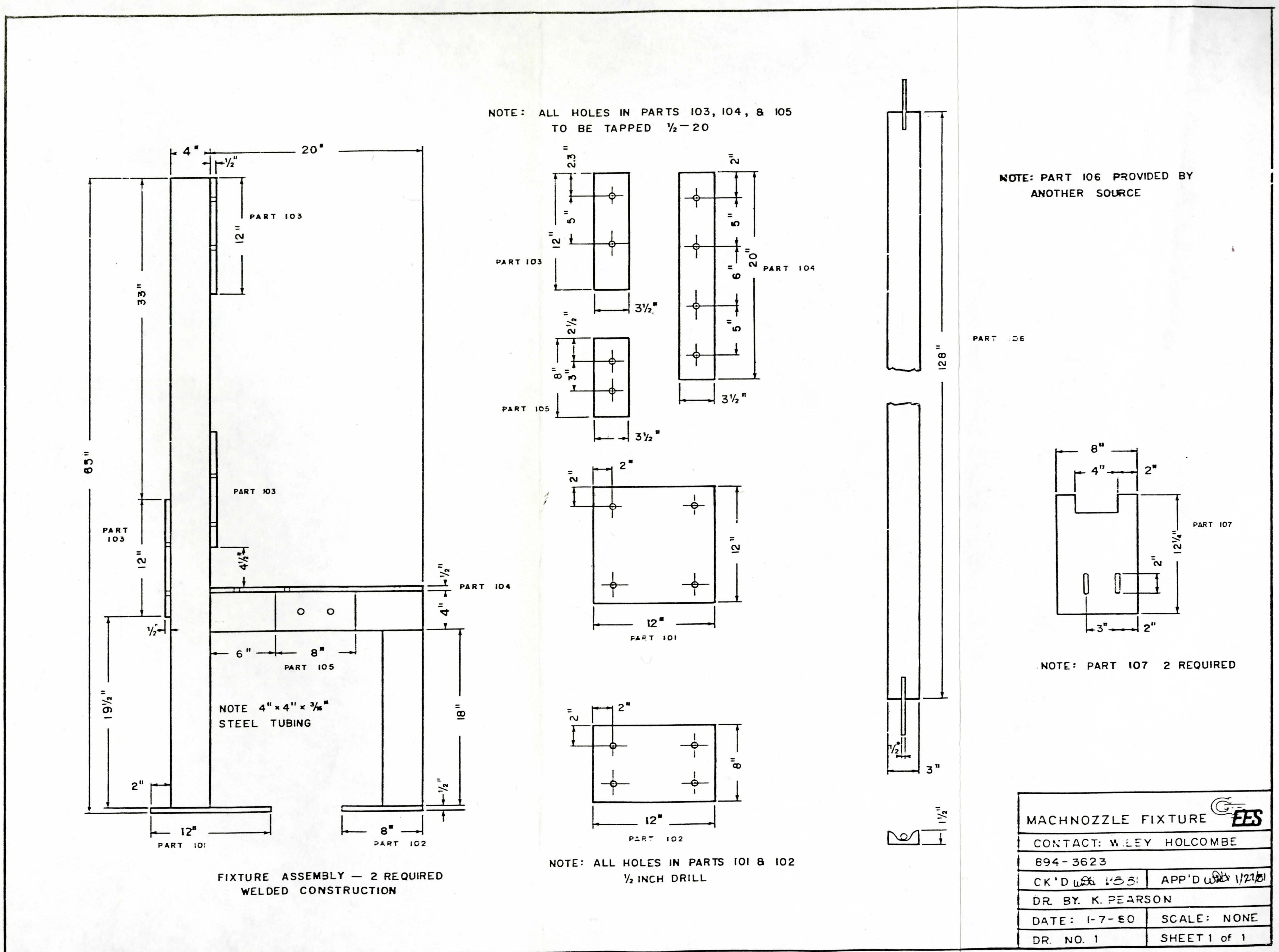
Problems with the initial condenser configuration resulted in considerable development work. The most important of these problems was the distribution of cooling water in the condenser column. The weir tray designs that were utilized proved unsatisfactory for the necessary cooling water flow rates. The nozzle that was used in the final configuration fit the requirement much better.

A large quantity of lint and impurities was blown out of the fabric. This waste stream, though quite hot, was too dirty to be mixed with the condenser output. The drain line for the waste stream must be large enough to handle the entrained lint.

The effectiveness of the seals on the steam collector trough largely determines the amount of stack loss from the condenser. The final configuration used polyester film seals which touched the running fabric and rigid wooden seals at the end. This method was very effective, however, the life of the polyester film seal is unknown. Further testing is needed.

The performance of the Machnozzle has been demonstrated on sheeting weight fabric; however, further testing is required on heavier fabrics. Tests should also be conducted to compare the performance of the Machnozzle on compressed air to that on steam. Operation on compressed air will eliminate the need for the condenser and associated equipment.

APPENDIX A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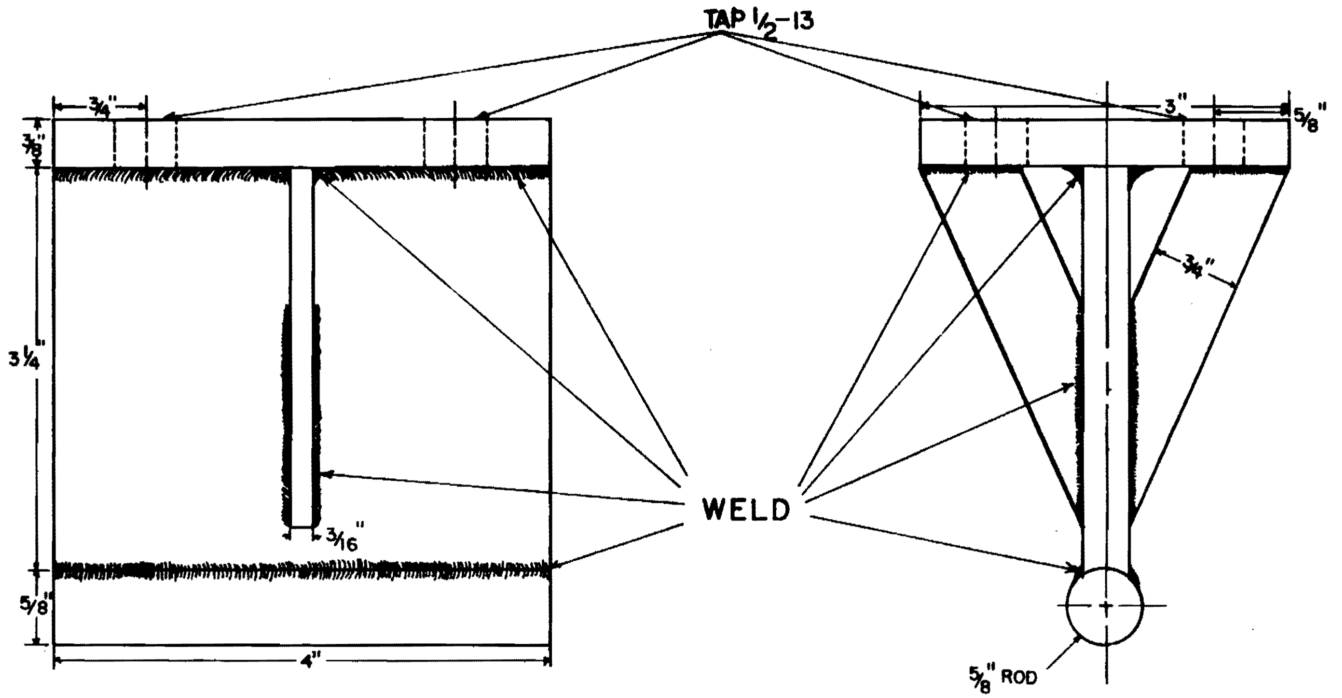
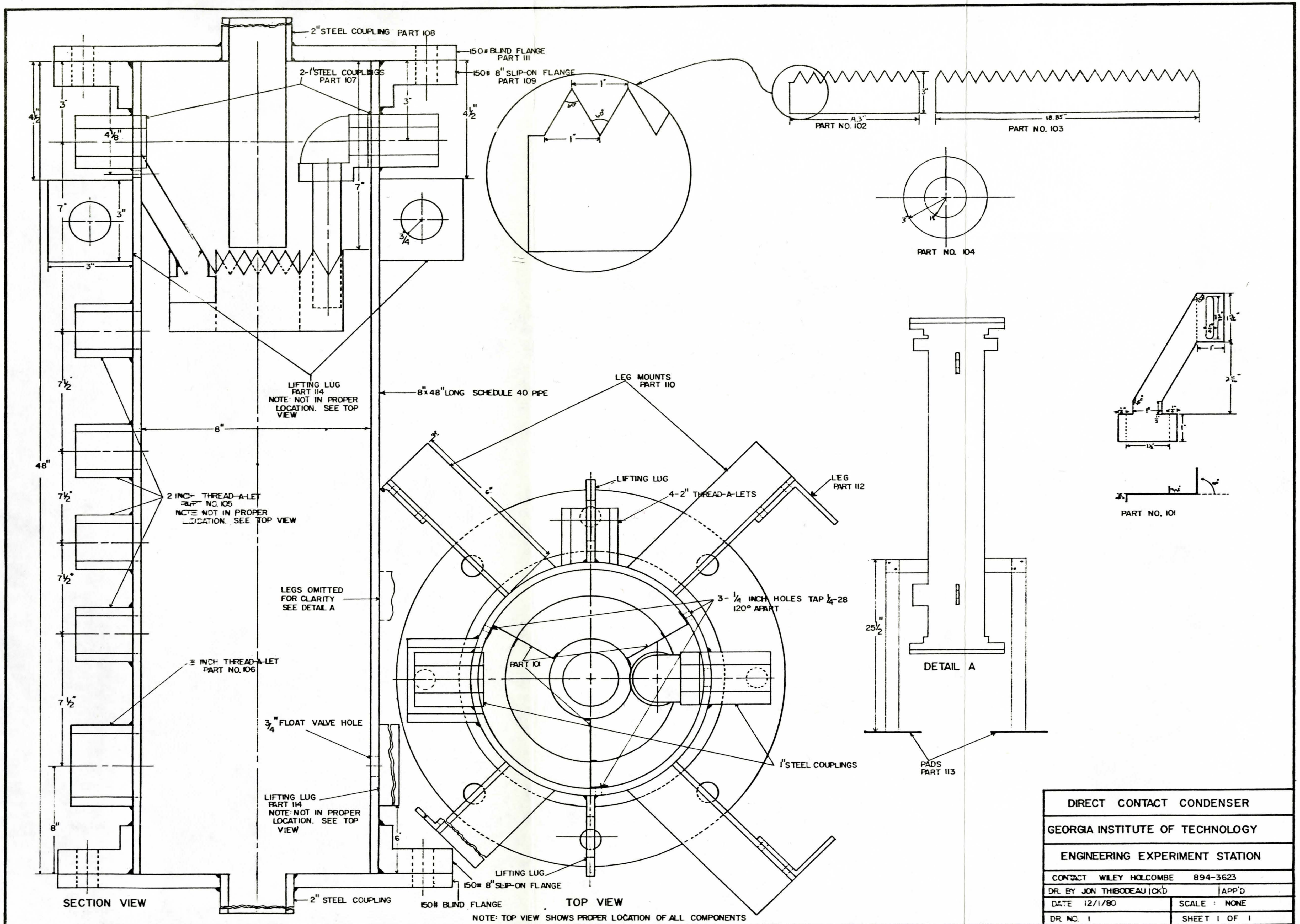
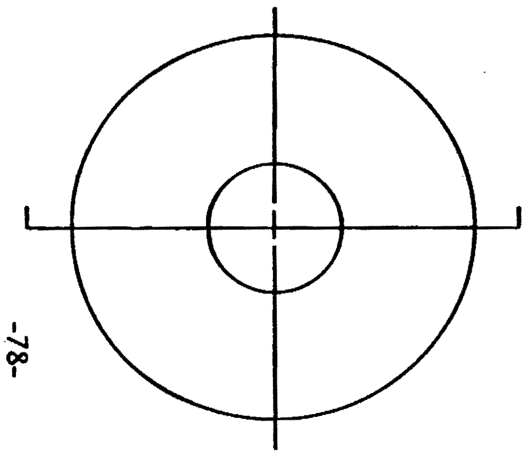
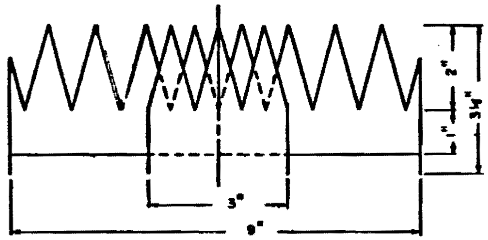
PART 103
PART 104
PART 105
PART 101
PART 102
NOTE: ALL HOLES IN PARTS 101 & 102 1/2 INCH DRILL
NOTE 4" x 4" x 3/16" STEEL TUBING
FIXTURE ASSEMBLY — 2 REQUIRED
WELDED CONSTRUCTION
NOTE: PART 106 PROVIDED BY ANOTHER SOURCE
PART 106
PART 107
NOTE: PART 107 2 REQUIRED
MACHNOZZLE FIXTURE
EES
CONTACT: W.LEY HOLCOMBE
894-3623
CK'D
APP'D
DR. BY. K. PEARSON
DATE: 1-7-80
SCALE: NONE
DR. NO. 1
SHEET 1 of 1



DUMMY MACHNOZZLE


2" STEEL COUPLING PART 108
150# BLIND FLANGE PART 111
2-1" STEEL COUPLINGS PART 107
150# 8" SLIP-ON FLANGE PART 109
PART NO. 102
PART NO. 103
PART NO. 104
LIFTING LUG PART 114 NOTE: NOT IN PROPER LOCATION. SEE TOP VIEW
8"x48" LONG SCHEDULE 40 PIPE
LEG MOUNTS PART 110
LIFTING LUG
4-2" THREAD-A-LETS
LEG PART 112
2 INCH THREAD-A-LET PART NO. 105 NOTE: NOT IN PROPER LOCATION. SEE TOP VIEW
LEGS OMITTED FOR CLARITY SEE DETAIL A
3- 1/4 INCH HOLES TAP 1/4-28 120° APART
PART 101
INCH THREAD-A-LET PART NO. 106
3/4" FLOAT VALVE HOLE
1" STEEL COUPLINGS
DETAIL A
PADS PART 113
PART NO. 101
LIFTING LUG PART 114 NOTE: NOT IN PROPER LOCATION. SEE TOP VIEW
LIFTING LUG
150# 8" SLIP-ON FLANGE
SECTION VIEW
2" STEEL COUPLING
150# BLIND FLANGE
TOP VIEW
NOTE: TOP VIEW SHOWS PROPER LOCATION OF ALL COMPONENTS
DIRECT CONTACT CONDENSER
GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
CONTACT WILEY HOLCOMBE 894-3623
DR. BY JON THIBODEAU | CK'D
APP'D
DATE 12/1/80
SCALE : NONE
DR. NO. 1
SHEET 1 OF 1

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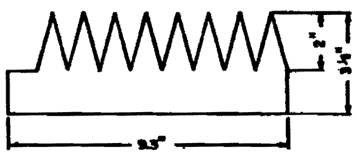
3 1/4"
1"
3"
9"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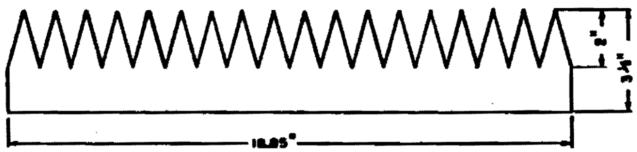
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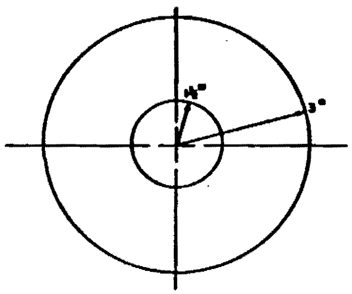
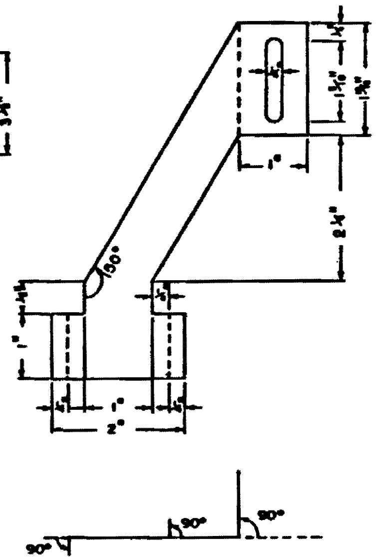
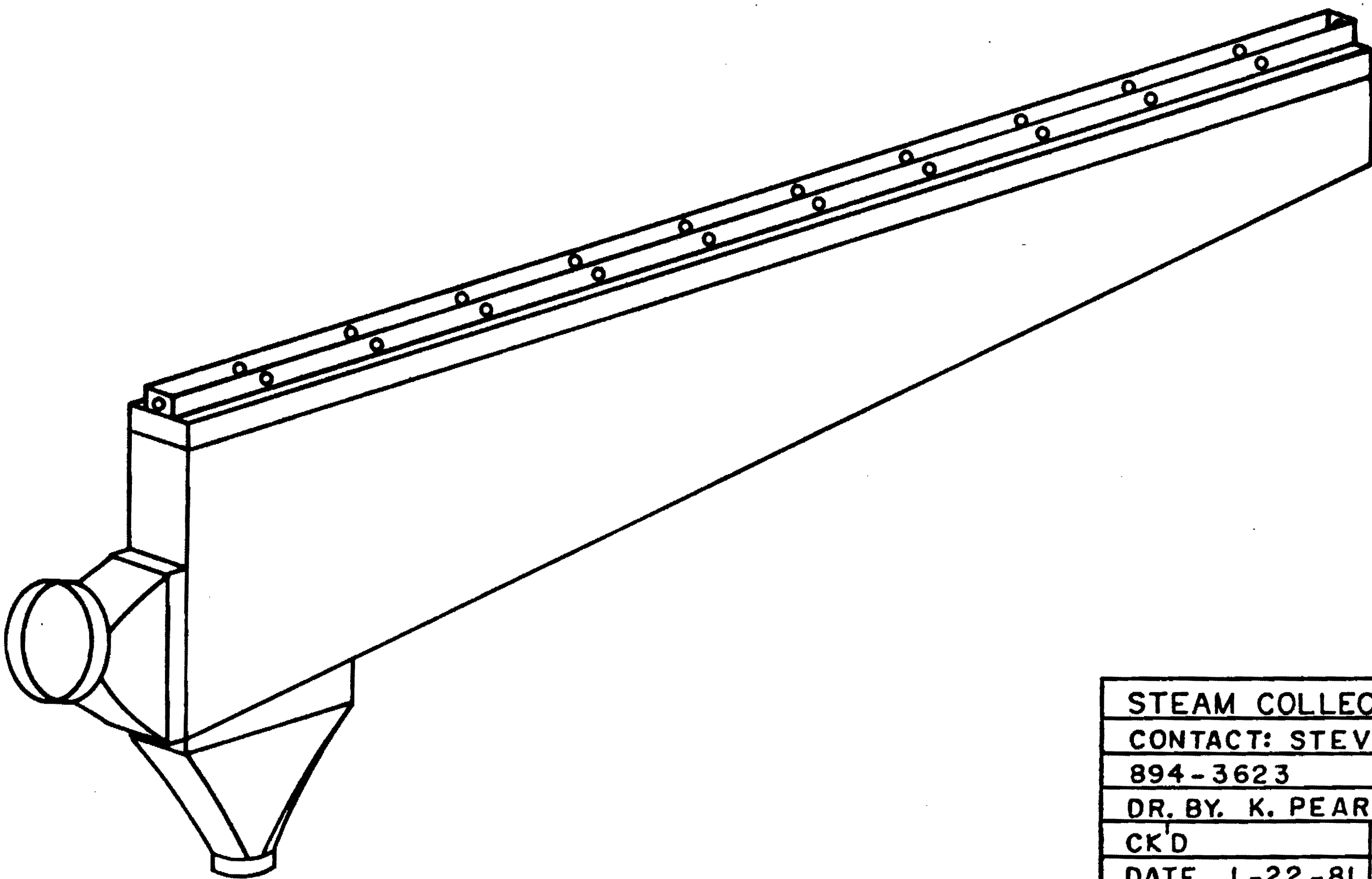
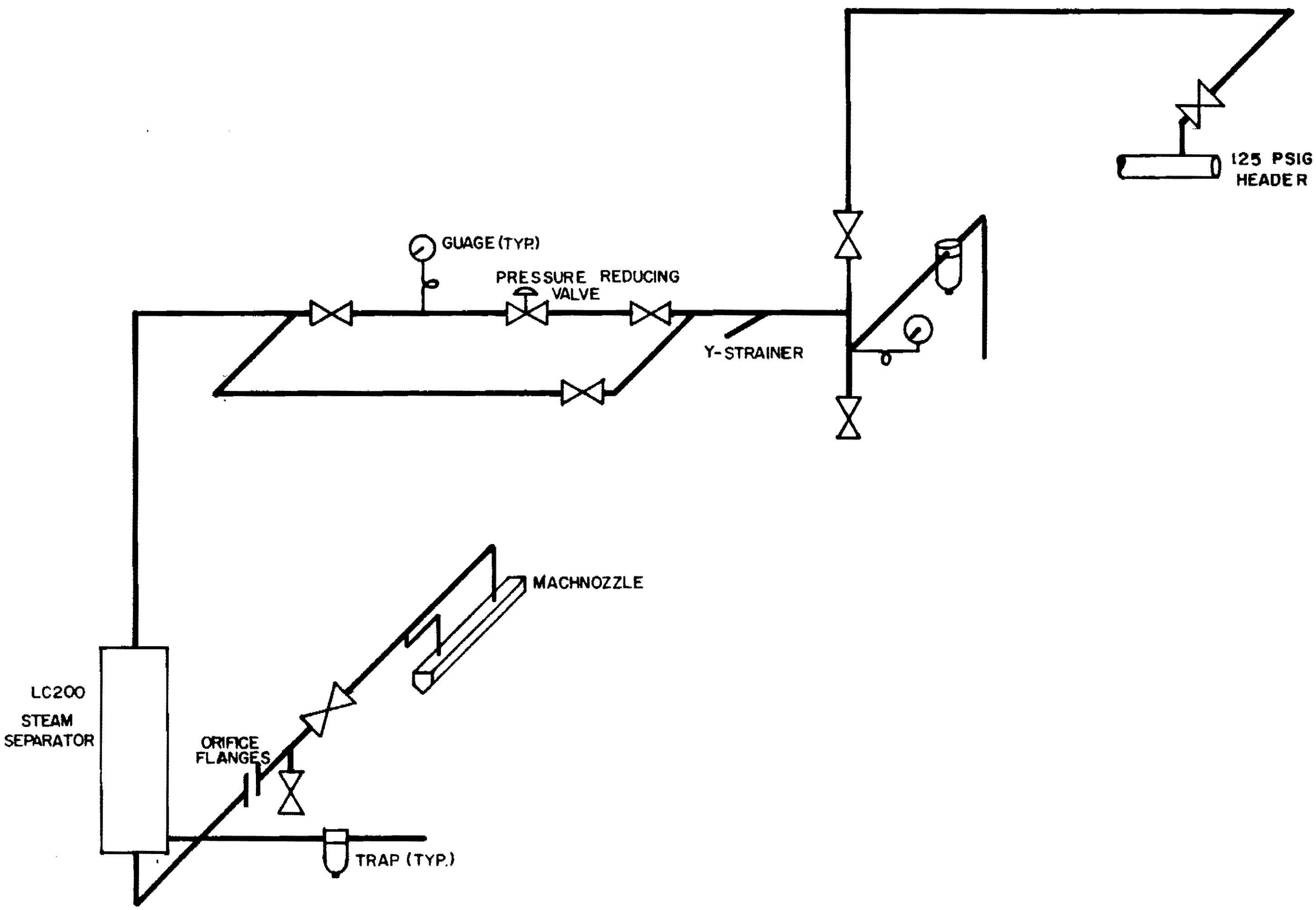
18.85"


1/2"
3"


150°
1"
2"
2 1/4"
90°
90°
90°



STEAM COLLECTOR TROUGH	
CONTACT: STEVE ROBERTSON	
894-3623	
DR. BY. K. PEARSON	
CK'D	APP'D
DATE 1-22-81	SCALE: NONE



FINAL STEAM PIPING CONFIGURATION

APPENDIX B

Moisture Monitoring Equipment:

Mahlo Microwave Moisture Monitor
Aqualot Type HMFR-7

Mahlo Portable Conductivity Moisture Monitor
Model DB7-7

Atmospheric Sciences', Inc. Portable Dielectric Moisture Monitor

Orifice Plates:

4-inch Main header
Bore - 2.662 inch β ratio - 0.6612   Meter constant - 4.885

2-inch line to first steam dryer can stack
Bore - 1.334 inch β ratio - 0.6455   Meter constant - 1.214

2-inch line to second steam dryer can stack
Bore - 1.334 inch β ratio - 0.6455   Meter constant - 1.214

2-inch line to third steam dryer can stack second set
Bore - 0.797 inch β ratio - 0.3854   Meter constant - 0.3982

2-inch line to fourth steam dryer can stack second set
Bore - 0.593 inch β ratio - 0.2869   Meter constant - 0.2188

1-inch line to Machnozzle
Bore - 0.682 inch β ratio - 0.650   Meter constant - 0.3130
Bore - 0.837 inch β ratio - 0.7982   Meter constant - 0.564

Steam Flow Monitors:

School of Textile Engineering Equipment

Foxboro Electronic differential pressure cell transmitter
Model Number   E13DM-HSAM2
Calibrated Range   0-100 inches of water

Foxboro Electronic Square Root Integrator
Model Number   66KST-OHB

Foxboro Flow Recorder
Model Number   40PR-RF1/EB-HA

Durant Digital Counter
6 digit, 24 V

Foxboro Power Supply

Model Number	N121AY

Purchased Equipment

Rosemont differential pressure transmitter, square root version

Model Number	1151DP-4-J-12-B1
Serial Number	280039
Calibrated Range	0-100 inches of water

Taylor electronic integrator

Model Number	1310 NK 14202
Serial Number	1310 NK 14202-11570B

Taylor single pen recorder, circular chart

Model Number	76JT1002
Serial Number	7JT1001A5058A

Durant digital counter

6 digit, 24 V

Portable steam flow monitor

Technology Diversified Incorporated

Model	TDI-100
Serial Numbers	A002A, B002A

Other Instrumentation:

Water meter on condenser

Model	Kent C700
Serial Number	80030788

Alnor Series 6000-P Velometer w/ low-flow probe

Serial Number	6077AA
Inventory Number	11B

Omegatemp Digital Thermocouple Readout Meter, Type K, °F

Model	HH-2
Serial Number	7040

APPENDIX C

Compilation of Data on Machnozzle Tests

Fabric Data Type 80/20 Textured Polyester/Cotton
Weight 2.99 oz/yd^2

		Regain (%)		STEAM		
					Flow Rate (LB/HR)	
Fabric Speed (YPM)	Number of Can Stacks	Before Machnozzle	After Machnozzle	Supply Pressure (PSIG)	Machnozzle Consumption	Steam Can Consumption
50	CONTROL					
		93				1002
	MACHNOZZLE TEST					
	1	93	57	20	155	682
	1	93	39	40	274	437
	1	93	32	60	380	345
	1	93	26	80	478	326
	1	93	21	100	552	317

Fabric Data Type 80/20 Textured Polyester/Cotton
Weight 2.91 oz/yd^2

		Regain (%)		STEAM		
					Flow Rate (LB/HR)	
Fabric Speed (YPM)	Number of Can Stacks	Before Machnozzle	After Machnozzle	Supply Pressure (PSIG)	Machnozzle Consumption	Steam Can Consumption
CONTROL						
75	4	85	-	-	-	2589
	3	85	-	-	-	2366
	2	85	-	-	-	2039
MACHNOZZLE TESTS						
	1	85	64	20	125	952
	1	85	49	40	204	817
	1	85	40	60	291	713
	1	85	33	80	375	653
	1	85	28	100	456	614
	1	85	26	110	473	587

Fabric Data Type 80/20 Textured Polyester/Cotton
Weight 2.99 oz/yd^2

		Regain (%)		STEAM		
					Flow Rate (LB/HR)	
Fabric Speed (YPM)	Number of Can Stacks	Before Machnozzle	After Machnozzle	Supply Pressure (PSIG)	Machnozzle Consumption	Steam Can Consumption
	CONTROL					
100	4	93	-	-	-	3148
	3	93	-	-	-	2652
	2	93	-	-	-	2348
	MACHNOZZLE TEST					
	1	93	62	20	175	1164
	1	93	48	40	283	967
	1	93	38	60	396	806
	1	93	32	80	495	608
	1	93	27	100	609	571

Fabric Data Type 80/20 Textured Polyester/Cotton
Weight 2.91 oz/yd^2

Fabric Speed (YPM)	Number of Can Stacks	Regain (%) Before Machnozzle	Regain (%) After Machnozzle	STEAM Supply Pressure (PSIG)	STEAM Flow Rate (LB/HR) Machnozzle Consumption	STEAM Flow Rate (LB/HR) Steam Can Consumption
125						
	CONTROL					
	2	90	-	-	-	2364
	MACHNOZZLE TESTS					
	1	90	45	60	360	1196
	1	90	35	80	425	1060
	1	90	32	100	525	847

Fabric Data Type 50/50 Polyester/Cotton Percale
Weight 3.36 oz/yd^2

		Regain (%)		STEAM		
					Flow Rate (LB/HR)	
Fabric Speed (YPM)	Number of Can Stacks	Before Machnozzle	After Machnozzle	Supply Pressure (PSIG)	Machnozzle Consumption	Steam Can Consumption
50						
	CONTROL					
	1	77	-	-	-	1183
	MACHNOZZLE TESTS					
	1	77	39	40	225	425
	1	77	28	60	338	333
	1	77	27	80	485	261
	1	77	25	95	533	213
75						
	CONTROL					
	4	75	-	-	-	2564
	3	75	-	-	-	2200
	2	75	-	-	-	1753
	1	75	-	-	-	978*
	MACHNOZZLE TESTS					
	1	75	24	80	454	485
	1	75	21	95	568	454

*Insufficient Number of Stacks of Cans for Normal Operation

Fabric Data Type Rerun 50/50 Polyester/Cotton Percale*
Weight 3.39 oz/yd^2 for 80 YPM
3.44 oz/yd^2 for 200 YPM

Fabric Speed (YPM)	Number of Can Stacks	Regain (%) Before Machnozzle	Regain (%) After Machnozzle	STEAM Supply Pressure (PSIG)	STEAM Flow Rate (LB/HR) Machnozzle Consumption	STEAM Flow Rate (LB/HR) Steam Can Consumption
80						
	CONTROL					
	2	60	-	-	-	1712
	1	60	-	-	-	1397
	MACHNOZZLE TESTS					
	1	60		20	138	1019
	1	60		40	240	897
	1	60		60	330	815
	1	60		80	430	693
	1	60		100	540	611
100						
	CONTROL					
	2	57	-	-	-	2077
	MACHNOZZLE TESTS					
	1	57	23	60	340	932
	1	57	18	80	432	757
	1	57	16	90	504	693

*Fabric had been previously dried.

Fabric Data Type 100% Cotton*
Weight 3.46 oz/yd^2

Fabric Speed (YPM)	Number of Can Stacks	Regain (%) Before Machnozzle	Regain (%) After Machnozzle	STEAM Supply Pressure (PSIG)	STEAM Flow Rate (LB/HR) Machnozzle Consumption	STEAM Flow Rate (LB/HR) Steam Can Consumption
	CONTROL---------STEAM CANS NOT USED ON COTTON					
	MACHNOZZLE TESTS					
	0	86	75	40	206	0
70	0	86	72	60	235	0
	0	86	64	80	408	0
	0	86	56	109	629	0

*No Shim In Machnozzle.

Fabric Data Type 65/35 Polyester/Cotton Percale
Weight 3.41 oz/yd^2

		Regain (%)		STEAM		
					Flow Rate (LB/HR)	
Fabric Speed (YPM)	Number of Can Stacks	Before Machnozzle	After Machnozzle	Supply Pressure (PSIG)	Machnozzle Consumption	Steam Can Consumption
75	CONTROL					
	4	73	-	-	-	2437
	3	73	-	-	-	2166
	2	73	-	-	-	1905
	MACHNOZZLE TESTS					
	1	73	62	20	99	1110
	1	73	45	40	210	883
	1	73	35	60	270	646
	1	73	29	80	399	586
	1	73	26	100	476	489
	1	73	24	115	509	449
50	CONTROL					
	1	73	-	-	-	874
	MACHNOZZLE TESTS					
	1	73	28	80	440	489

Fabric Data Type 65/35 Polyester/Cotton Muslin
Weight 3.39 oz/yd^2

Fabric Speed (YPM)	Number of Can Stacks	Regain (%)		STEAM		
					Flow Rate (LB/HR)	
		Before Machnozzle	After Machnozzle	Supply Pressure (PSIG)	Machnozzle Consumption	Steam Can Consumption
75	CONTROL					
	4	77	-	-	-	2685
	2	77	-	-	-	1876
	MACHNOZZLE TESTS					
	1	77	46	40	253	915
	1	77	34	60	354	790
	1	77	23	80	471	650
	1	77	19	100	572	556
100	CONTROL					
	4	77	0	-	-	3114
	2	77	0	-	-	2339
	MACHNOZZLE TESTS					
	1	77	44	60	352	1079
	1	77	29	80	465	770
	1	77	27	100	571	NO DATA

Fabric Data Type 65/35 Polyester/Cotton Muslin
Weight 3.42 oz/yd^2

		Regain (%)		STEAM		
					Flow Rate (LB/HR)	
Fabric Speed (YPM)	Number of Can Stacks	Before Machnozzle	After Machnozzle	Supply Pressure (PSIG)	Machnozzle Consumption	Steam Can Consumption
115						
	CONTROL					
	4	74	-	-	-	3236
	3	74	-	-	-	2856
	2	74	-	-	-	2487
	MACHNOZZLE TESTS					
	2	74	60	40	171	1958
	2	74	47	60	324	1916
	2	74	37	80	420	1768
	2	74	27	100	531	1754

Fabric Data Type 65/35 Polyester/Cotton Muslin
Weight 3.45 oz/yd^2

		Regain (%)		STEAM		
					Flow Rate (LB/HR)	
Fabric Speed (YPM)	Number of Can Stacks	Before Machnozzle	After Machnozzle	Supply Pressure (PSIG)	Machnozzle Consumption	Steam Can Consumption
115	CONTROL					
	4	81	-	-	-	3251
	3	81	-	-	-	2868
	2	81	-	-	-	2478
	MACHNOZZLE TESTS*					
	2	81	-	106	464	1888

*No Shim In Machnozzle.

Results of Condenser Tests

Fabric: 65/35 Polyester/Cotton Muslin

Weight: 3.42 oz/yd^2

Speed: 100 ypm

Condenser Run 1

	Flow Rate (lb/hr)	Temperature (°F)	Regain (%)
Steam to Machnozzle	412 @60psig		
Fabric	1568		
IN		68	87
OUT		165	54
Cooling Water	4350	65	
Condenser Discharge		127	
Wastewater Stream		201	
Air	205		
IN(wet/dry bulb)		64/72	
OUT(wet/dry bulb)		110/112	

Condenser Run 2

	Flow Rate (lb/hr)	Temperature (°F)	Regain (%)
Steam to Machnozzle	412 @60psig		
Fabric	1568		
IN		68	87
OUT		178	51
Cooling Water	5000	65	
Condenser Discharge		117	
Wastewater Stream		196	
Air	209		
IN(wet/dry bulb)		64/72	
OUT(wet/dry bulb)		100/103	

Condenser Run 3

	Flow Rate (lb/hr)	Temperature (°F)	Regain (%)
Steam to Machnozzle	464 @80psig		
Fabric	1568		
IN		68	87
OUT		175	39
Cooling Water	6555	65	
Condenser Discharge		118	
Wastewater Stream		205	
Air	149		
IN(wet/dry bulb)		64/71	
OUT(wet/dry bulb)		76/91	

Condenser Run 4

	Flow Rate (lb/hr)	Temperature (°F)	Regain (%)
Steam to Machnozzle	464 @80psig		
Fabric	1568		
IN		68	87
OUT		175	41
Cooling Water	5549	65	
Condenser Discharge		132	
Wastewater Stream		205	
Air	148		
IN(wet/dry bulb)		64/71	
OUT(wet/dry bulb)		83/88	

Condenser Run 5

	Flow Rate (lb/hr)	Temperature (°F)	Regain (%)
Steam to Machnozzle	464 @80psig		
Fabric	1568		
IN		68	87
OUT		175	40
Cooling Water	4955	65	
Condenser Discharge		142	
Wastewater Stream		207	
Air	170		
IN(wet/dry bulb)		64/71	
OUT(wet/dry bulb)		90/93	

Condenser Run 6

	Flow Rate (lb/hr)	Temperature (°F)	Regain (%)
Steam to Machnozzle	464 @80psig		
Fabric	1568		
IN		68	87
OUT		175	38
Cooling Water	4391	65	
Condenser Discharge		148	
Wastewater Stream		206	
Air	181		
IN(wet/dry bulb)		64/71	
OUT(wet/dry bulb)		90/93	

Condenser Run 7

	Flow Rate (lb/hr)	Temperature (°F)	Regain (%)
Steam to Machnozzle	464 @80psig		
Fabric	1568		
IN		68	87
OUT		175	38
Cooling Water	3791	65	
Condenser Discharge		164	
Wastewater Stream		205	
Air	135		
IN(wet/dry bulb)		64/71	
OUT(wet/dry bulb)		105/108	

APPENDIX D

EQUIPMENT COST ESTIMATES FOR 120-INCH MACHNOZZLE

Machnozzle	$ 9650*	$ 9650*
Mounting Fixture	1625	1625
Filter	227	4906*
Installation	800	800*
Machnozzle Total	$12302	$16981
Condenser	$2100	$21509*
Trough	1500	
Outlet Pump	785	
Installation	800	800*
Condenser Total	$5185	$22309

*From a quotation by J-Tex, Inc. to J.P. Stevens and Co., Inc. in August 1981.

Results of the Economic Analysis

for the Higher Equipment Cost Estimate

Fuel Price ($\$/10^6$Btu)	Fabric Speed (YPM)	Without Condenser NPV ($)	B/C	Simple Payback (YR)	With Condenser NPV ($)	B/C	Simple Payback (YR)
3.50	50	74,811	5.41	1.39	171,048	5.35	1.39
3.50	75	174,797	11.29	.70	301,585	8.68	.89
3.50	100	251,175	15.79	.51	404,348	11.29	.70
3.50	115	327,553	20.29	.40	480,726	13.24	.60
3.50	125	315,054	19.55	.41	464,987	12.83	.62
5.00	50	110,868	7.53	1.02	251,878	7.41	1.03
5.00	75	253,645	15.94	.50	438,282	12.16	.65
5.00	100	362,712	22.36	.36	585,026	15.89	.50
5.00	115	471,778	28.78	.28	694,092	18.67	.43
5.00	125	453,931	27.73	.29	671,618	18.09	.44
6.50	50	147,097	9.66	.81	333,096	9.48	.82
6.50	75	332,873	20.60	.39	575,637	15.65	.15
6.50	100	474,785	28.96	.28	766,573	20.51	.39
6.50	115	616,697	37.32	.22	908,485	24.12	.34
6.50	125	593,475	35.95	.23	879,242	23.38	.35

Results of the Economic Analysis

for the Lower Equipment Cost Estimate

		Without Condenser			With Condenser		
Fuel Price ($/$10^6$Btu)	Fabric Speed (YPM)	NPV ($)	B/C	Simple Payback (YR)	NPV ($)	B/C	Simple Payback (YR)
3.50	50	76,568	7.22	1.06	179,236	11.25	.70
3.50	75	176,554	15.35	.52	309,773	18.71	.43
3.50	100	252,932	21.56	.38	412,535	24.59	.33
3.50	115	329,310	27.77	.29	488,913	28.96	.28
3.50	125	316,811	26.75	.30	473,175	28.06	.29
5.00	50	112,625	10.15	.77	260,065	15.87	.50
5.00	75	255,402	21.76	.37	446,470	26.53	.31
5.00	100	364,469	30.63	.27	593,214	34.92	.23
5.00	115	473,535	39.49	.21	702,280	41.16	.20
5.00	125	455,688	38.04	.22	679,806	39.87	.21
6.50	50	148,854	13.10	.61	341,284	20.52	.39
6.50	75	334,630	28.20	.29	583,824	34.39	.24
6.50	100	476,542	39.74	.21	774,760	45.30	.18
6.50	115	618,454	51.27	.16	916,672	53.42	.15
6.50	125	595,232	49.38	.17	887,430	51.75	.16

TYPICAL 43.3-INCH MACHNOZZLE PERFORMANCE
FOR A FABRIC SPEED OF 50 YPM

Pressure (psig)	R_{IN} (%)	R_{OUT} (%)	R (%)	M_W (LBW/HR)	M_S (LBS/HR)	Steam Savings (LBS/HR) Without Condenser	With Condenser
0	75	75	0	0	0	0	0
20	75	57	18	138	139	68	158
40	75	39	36	275	231	182	332
60	75	30	45	344	341	175	397
80	75	27	48	367	445	106	399
100	75	23	52	397	537	59	408

TYPICAL 43.3-INCH MACHNOZZLE PERFORMANCE
FOR A FABRIC SPEED OF 75 YPM

Pressure (psig)	R_{IN} (%)	R_{OUT} (%)	R (%)	M_W (LBW/HR)	M_S (LBS/HR)	Steam Savings (LBS/HR) Without Condenser	Steam Savings (LBS/HR) With Condenser
0	75	75	0	0	0	0	0
20	75	63	12	138	139	68	158
40	75	47	28	321	231	251	401
60	75	36	39	447	341	330	551
80	75	26	49	562	445	398	687
100	75	24	51	585	537	341	690

TYPICAL 43.3-INCH MACHNOZZLE PERFORMANCE
FOR A FABRIC SPEED OF 100 YPM

Pressure (psig)	R_{IN} (%)	R_{OUT} (%)	R (%)	M_W (LBW/HR)	M_S (LBS/HR)	Steam Savings (LBS/HR) Without Condenser	With Condenser
0	75	75	0	0	0	0	0
20	75	62	13	199	139	160	250
40	75	48	27	412	231	387	537
60	75	41	34	519	341	438	659
80	75	31	44	672	445	563	852
100	75	27	48	733	537	563	912

TYPICAL 43.3-INCH MACHNOZZLE PERFORMANCE
FOR A FABRIC SPEED OF 115 YPM

Pressure (psig)	R_{IN} (%)	R_{OUT} (%)	R (%)	M_W (LBW/HR)	M_S (LBS/HR)	Steam Savings (LBS/HR) Without Condenser	With Condenser
0	75	75	0	0	0	0	0
20	75	--	--	---	139	---	----
40	75	60	15	263	231	164	314
60	75	47	28	492	341	397	619
80	75	37	38	667	445	556	845
100	75	27	48	843	537	728	1077

TYPICAL 43.3-INCH MACHNOZZLE PERFORMANCE
FOR A FABRIC SPEED OF 125 YPM

Pressure (psig)	R_{IN} (%)	R_{OUT} (%)	R (%)	M_W (LBW/HR)	M_S (LBS/HR)	Steam Savings (LBS/HR) Without Condenser	With Condenser
0	75	75	0	0	0	0	0
20	75	--	--	---	139	---	----
40	75	--	--	---	231	---	----
60	75	45	30	573	341	519	740
80	75	35	40	764	445	701	990
100	75	32	43	821	537	695	1043

Net Present Value and Benefit-to-Cost
Ratio Calculations

```
 10 REM COST OF MACHNOZZLE IS A(
    1) ($)
 20 REM COST OF CONDENSER IS A(2
    ) ($)
 30 REM ANNUAL MAINTENANCE COST
    IS A(3) ($/YR)
 40 REM INVESTMENT TAX CREDIT IS
     10% OF THE COST
 50 REM DISCOUNT RATE IS A(4)
 60 REM INCREMENTAL TAX RATE IS
    48%
 70 REM ANNUAL OPERATING HOURS A
    (5) (HRS/YR)
 80 REM SAVINGS RATE IS A(6) (LB
    SOF STEAM/HR)
 90 REM CURRENT FUEL PRICE IS A(
    7) ($/10^6BTU)
100 REM FUEL ESCALATION RATE IS
    A(8) ( /YR)
110 REM INTEREST RATE IS A(9) (
    /YR)
120 REM INFLATION RATE IS A(10)
    ( /YR)
130 REM DECLINING BALANCE RATE I
    S 2
140 REM CONDENSER SAVINGS IS A(1
    1) (LBS OF STEAM/HR)
150 REM SYSTEM LIFE AND DEPRECIA
    TION LIFE IS A(12)
160 ASSIGN# 1 TO "DATA3"
165 PRINT "MNREAD,9/16/81"
166 PRINT "DATA3"
170 DIM A(50)
180 A(1)=14556
190 A(2)=21509
210 A(3)=1000
220 F1=.1*A(1)
230 A(4)=.15
240 F2=.48
250 A(5)=6900
260 A(6)=182
270 A(7)=3.5
280 A(8)=.2
290 A(9)=.15
300 A(10)=.1
310 A(11)=408
320 FOR J=1 TO 30
330 READ# 1 ; A(1),A(2),A(6),A(1
    1),A(7)
340 A(12)=7
345 A(13)=A(1)+A(2)
350 A(14)=-A(12)
360 IF A(2)>0 THEN S1=1150*A(11)
    *A(5) ELSE S1=1150*A(6)*A(5)
```

```
370 IF A(4)=A(8) THEN 410
380 G=(1+A(4))/(1+A(8))-1
390 P1=A(7)*S1*(1-(1+G)^(-1*A(12
    )))/(G*1000000)
400 GOTO 420
410 P1=A(7)*A(12)*S1/1000000
420 IF A(4)=A(10) THEN 460
430 G2=(1+A(4))/(1+A(10))-1
440 P2=A(3)*(1-(1+G2)^(-1*A(12))
    )/G2
450 GOTO 470
460 P2=A(3)*A(12)
470 D=2/A(12)
480 B=(1-D)/(1+A(4))
490 P3=D*A(13)*(1-B^A(12))/((1+A
    (4))*(1-B))
500 IF A(4)=A(9) THEN 540
510 B1=(1+A(9))/(1+A(4))
520 Z2=(1+A(9))^A(14)*(1-B1^A(12
    ))/(1+A(4))/(1-B1)
530 GOTO 550
540 Z2=A(12)*(1+A(4))^(A(14)-1)
550 Z1=(1-(1+A(4))^A(14))/A(4)
560 P4=A(13)*A(9)*(Z1-Z2)/(1-(1+
    A(9))^A(14))
570 N=A(13)-.1*A(13)/(1+A(4))+(1
    -F2)*(-P1+P2)-F2*P3-(1-F2)*P
    4
580 N=-N
590 C0=A(13)
600 B0=P1*(1-F2)+.1*A(13)/(1+A(4
    ))-(1-F2)*P2+P3*F2+P4*(1-F2)
610 Q=B0/C0
620 FOR I=1 TO 13
630 PRINT "A(";I;")    ";A(I)
640 NEXT I
650 PRINT USING 660 ; N
660 IMAGE "NPV IS",DDDDDDD.DD
670 PRINT USING 680 ; Q
680 IMAGE "BENEFIT TO COST IS",D
    DDD.DD
690 PRINT
700 PRINT
710 NEXT J
720 ASSIGN# 1 TO *
730 END
```

Simple Payback Calculation

```
 10 DIM A(25)
 20 ASSIGN# 1 TO "DATA4"
 25 PRINT "SIMF2"
 26 PRINT "DATA4"
 30 FOR J=1 TO 30
 40 READ# 1 ; A(1),A(2),A(6),A(1
    1),A(7)
 50 A(13)=A(1)+A(2)
 60 A(15)=.1*A(13)
 70 IF A(2)>0 THEN A(16)=A(11)*6
    900*1150*A(7)/1000000 ELSE A
    (16)=A(6)*6900*1150*A(7)/100
    0000
 80 A(17)=2/7*A(13)
 90 A(18)=.15*A(13)
100 A(19)=A(15)+.52*A(16)-520+.4
    8*A(17)-.52*A(18)
110 A(20)=A(13)/A(19)
120 A(21)=A(13)-A(19)
130 A(22)=.52*1.2*A(16)-1.1*520+
    .48*2/7*(A(13)-A(17))-.52*.1
    5*A(13)*.9096396
140 A(23)=1+A(21)/A(22)
320 PRINT A(19);A(20)
330 IF A(21)>0 THEN PRINT A(23)
    ELSE PRINT "LESS THAN ONE YE
    AR"
340 PRINT
350 NEXT J
360 ASSIGN# 1 TO *
370 END
```

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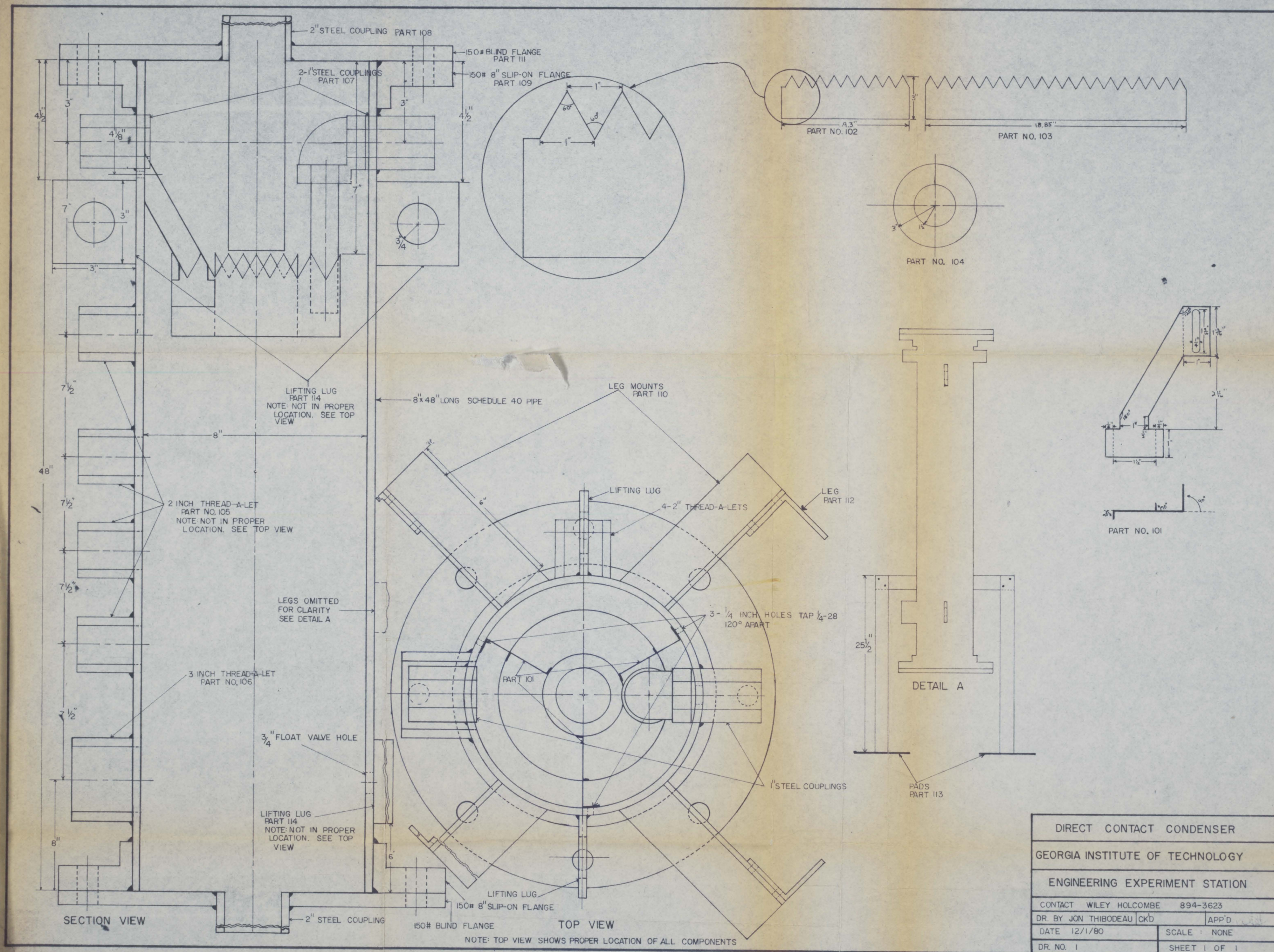
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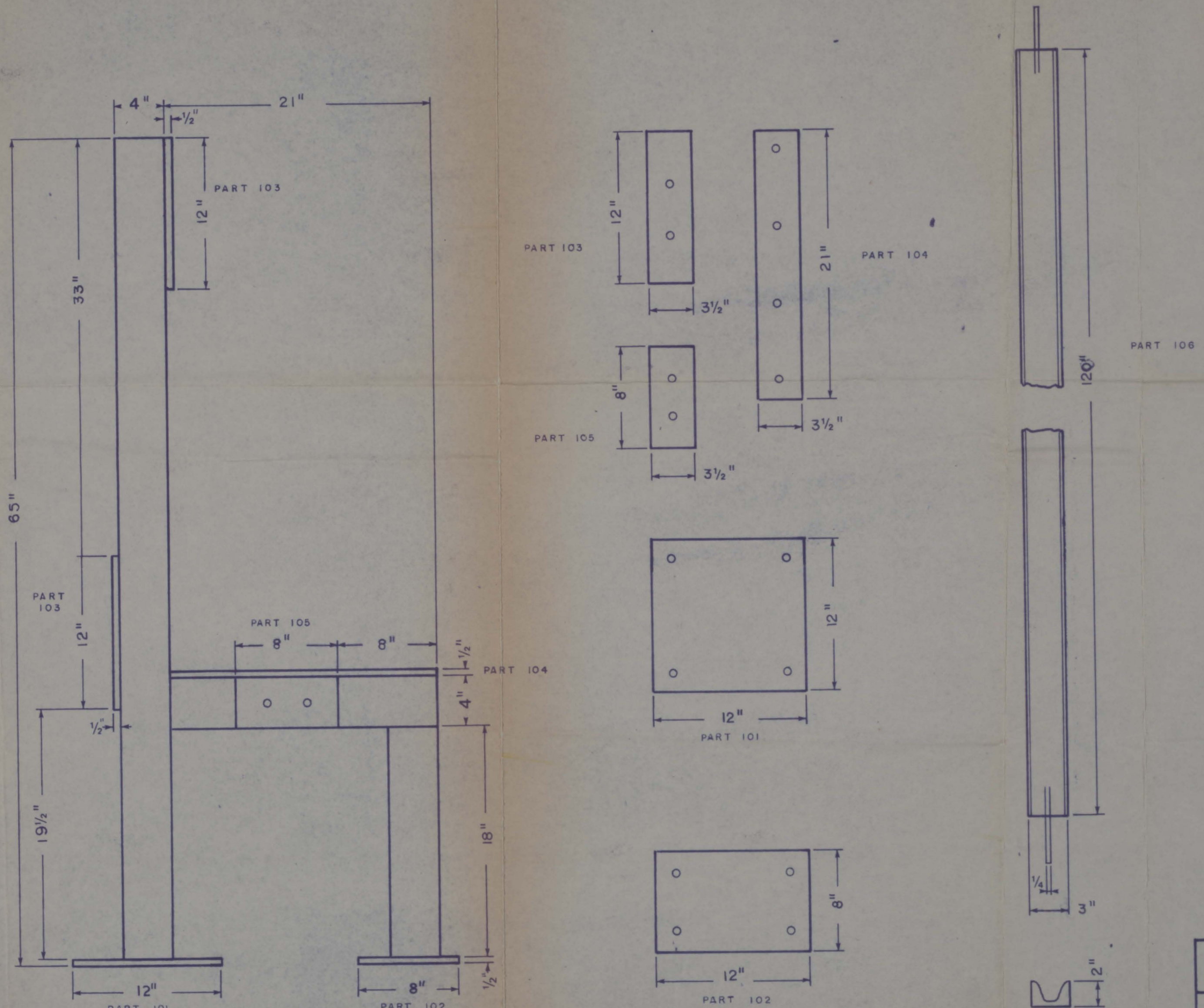
150# BLIND FLANGE PART 111
150# 8" SLIP-ON FLANGE PART 109
2-1" STEEL COUPLINGS PART 107
LIFTING LUG PART 114 NOTE: NOT IN PROPER LOCATION. SEE TOP VIEW
8" x 48" LONG SCHEDULE 40 PIPE
2 INCH THREAD-A-LET PART NO. 105 NOTE NOT IN PROPER LOCATION. SEE TOP VIEW
3 INCH THREAD-A-LET PART NO. 106
LEGS OMITTED FOR CLARITY SEE DETAIL A
3/4" FLOAT VALVE HOLE
LIFTING LUG PART 114 NOTE: NOT IN PROPER LOCATION. SEE TOP VIEW
2" STEEL COUPLING
SECTION VIEW
150# 8" SLIP-ON FLANGE
150# BLIND FLANGE
PART NO. 102
PART NO. 103
PART NO. 104
LEG MOUNTS PART 110
LIFTING LUG
4-2" THREAD-A-LETS
LEG PART 112
3- 1/4 INCH HOLES TAP 1/4-28 120° APART
PART 101
1" STEEL COUPLINGS
LIFTING LUG
TOP VIEW
NOTE: TOP VIEW SHOWS PROPER LOCATION OF ALL COMPONENTS
DETAIL A
PADS PART 113
PART NO. 101
DIRECT CONTACT CONDENSER
GEORGIA INSTITUTE OF TECHNOLOGY
ENGINEERING EXPERIMENT STATION
CONTACT WILEY HOLCOMBE 894-3623
DR. BY JON THIBODEAU
CK'D
APP'D
DATE 12/1/80
SCALE : NONE
DR. NO. 1
SHEET 1 OF 1



MACHNOZZLE FIXTURE GT EES	
CONTACT: WILEY HOLCOMBE	
894-3623	
CK'D WDH 1/8/81	APP'D
DR. BY. K. PEARSON	
DATE: 1-7-80	SCALE: NONE
DR. NO. 1	SHEET 1 of 1